In March 1968 a Soviet submarine was lost with all hands 16,500 feet below the surface of the Pacific Ocean. On 8 August 1974 [redacted] (b)(1) *that submarine was brought to the surface in the giant talons of a recovery system designed and developed specifically for that mission. The story of Project AZORIAN was told in Volume 22 Number 3 (Fall 1978) of* Studies in Intelligence. *This article, the last in a series, recounts, in language understandable to the general reader, the technological marvels that were the essence of the project.*

ENGINEERING FOR AZORIAN

[redacted] (b)(3)(c)

The engineering aspects of the AZORIAN program were a challenge which many thought rivaled that of a space program. It had been said that we knew more about the backside of the moon than the bottom of the ocean. Now the CIA engineers and management were being asked to undertake in an unstudied abyss an engineering marvel: in one gigantic effort, pull an estimated 3,920,000 pounds of wrecked submarine out of the ocean bottom and lift it intact over three miles into a surface ship. Never had such a feat been accomplished. CIA was being tasked to do it in not only a poorly understood environment, but also in record time. And no one was to know about it. If the United States could get its hands on the Soviet submarine's code books and machines, the nuclear weapons, the strategic plans, and . . . well, it was just plain too good to be true. Their potential value was inestimable. To have it all tomorrow would hardly be soon enough. These were the pressures CIA felt, especially the line managers and engineers.

There is no way to describe the engineering for Project AZORIAN without bringing in facts and figures. To many people, this promises to be dull, boring and tranquilizing. Yet to ignore them leaves a gaping hole in the AZORIAN story. For it was these very facts and figures, so fascinating to the engineer and so fearsome to the layman, that proved the project's feasibility.They and the engineers who made them a reality were the true underpinnings of Project AZORIAN.

Feasibility Studies

Because the target was judged to be of great value to the intelligence community, the higher echelons of the U.S. Goverment had decided it was a "go" situation before the technical feasibility studies were completed. Those were the days in which it was assumed American technology could solve any problem. The Agency engineers studied three methods of lifting the target: direct lift; trade ballast/buoyancy; and *in situ* generation of buoyancy. [redacted] (b)(1)

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as the new baseline (Figure 2). The original *Studies In Intelligence* article describes these early efforts and recounts the story of the program in detail.

Impinging on the feasibility studies was the fact that the recovery system was to be used in a one-time effort. There was no way in which a full-scale test could be run within the time, fiscal, or design constraints. To design, build, and test the recovery and lift equipment for multiple use would have increased the costs to an unacceptable level. AZORIAN would be a single-shot, go-for-broke effort.

To turn a "go" situation into a "go" decision for the U.S. Government, three fundamental questions needed to be answered. One of the answers was provided early in 1970 by the drilling ship *Glomar Challenger*, operated by Global Marine Inc. for the National Science Foundation. The question was, "Can a large surface ship maintain a position accurately enough at sea in order to lower a string of pipe to an exact geographic position on the ocean bottom?" The answer was a resounding yes. The *Challenger* rig had drilled a hole in the deep ocean floor, withdrawn the drill bit, and then successfully re-entered the hole. This feat required maintaining the surface ship within a circle whose radius was of the order of 15 feet.

The other two questions involved the heavy lift portion of the recovery system, in particular the heavy lift pipe. One question concerned the ability to make pieces of pipe of the requisite strength and quality in large numbers. The other concerned the effects on the ship and its drilling platform if the pipe string should break while under maximum load. This could transform a controlled, 17-million-pound, relatively static load into an uncontrolled dynamic one. Or, as the Deputy Director, Research and Engineering for the Department of Defense (a nuclear physicist) stated when first advised of the magnitude of the effect, "That's the energy equivalent of setting off a nuclear explosive of 8 kilotons." Needless to say, such an analogy did not lessen the concerns of management. Satisfactory answers to these questions and others were not in hand in the early days. They were arrived at later. But the lack of answers at this time did not stall the program, thanks to an important decision made by management.

A Courageous Decision

The project managers made a key decision in the fall of 1970: design and construction of the hardware would proceed on a concurrent basis. Several factors led to this decision. There were perishable aspects to the program including the cryptographic material being sought, the cover and the security. The yearly two-month weather window for the operation also was a factor. A delay of two months in the design and construction meant a 12-month slip in the operation. A delay of this magnitude would add maintenance costs to the program and magnify the chances of cover and security erosion. Nothing was simple; all factors were inextricably tied together. With the knowledge available at the time, the only prudent decision was to go ahead on a concurrent basis. To wait until all technical risks were resolved would mean not only more dollars, but perhaps no mission at all.

In October 1970 the engineering staff faced 11 major unknowns or technical risk areas. Problems existed in all elements of the program and included such basic items as the exact dimension and condition of the target, the ship design, the working machinery to provide the lift capability, the pipe string, [redacted] (b)(1) The unknowns and their individual solutions presented a frightening array of interfaces still to be resolved.

Four to eight months for each of the 11 unknowns were estimated as necessary to get better definitions; they totaled 60 months in all. If the engineers had to wait for a

(b)(1)

Figure 2. Schematic drawing of recovery sequence

sequential resolution of each of the risk areas, at least three to four years could be added to the schedule. Furthermore, the entanglement of each of the items with all the rest meant that a solution to one affected all the others. No final solution could be obtained until all were resolved. The only way to handle the situation was to start the design and construction on a concurrent basis, recognizing that changes would have to be made and that the designs would have to be kept flexible to accommodate them. In fact, senior management at the national level recognized that in some cases we might have to build the hardware in order to resolve the problems; design alone would not be able to do it. This proved to be prescience of the first order with regard to the pipe handling system and also the ship itself.

The concurrent design/construction philosophy that kept flexibility in the program paid off handsomely in an area that was not fully anticipated in the fall of 1970. (b)(1) [redacted] To fit the target inside the ship required that the well be widened, which in turn added 10 feet to the beam—the width—of the ship. While this caused a dollar increase in the program, the other alternative would have been more costly. (b)(1) [redacted] In this aspect alone, program costs would have been greater than those under the concurrent design/construction philosophy because of the additional year of program activity.

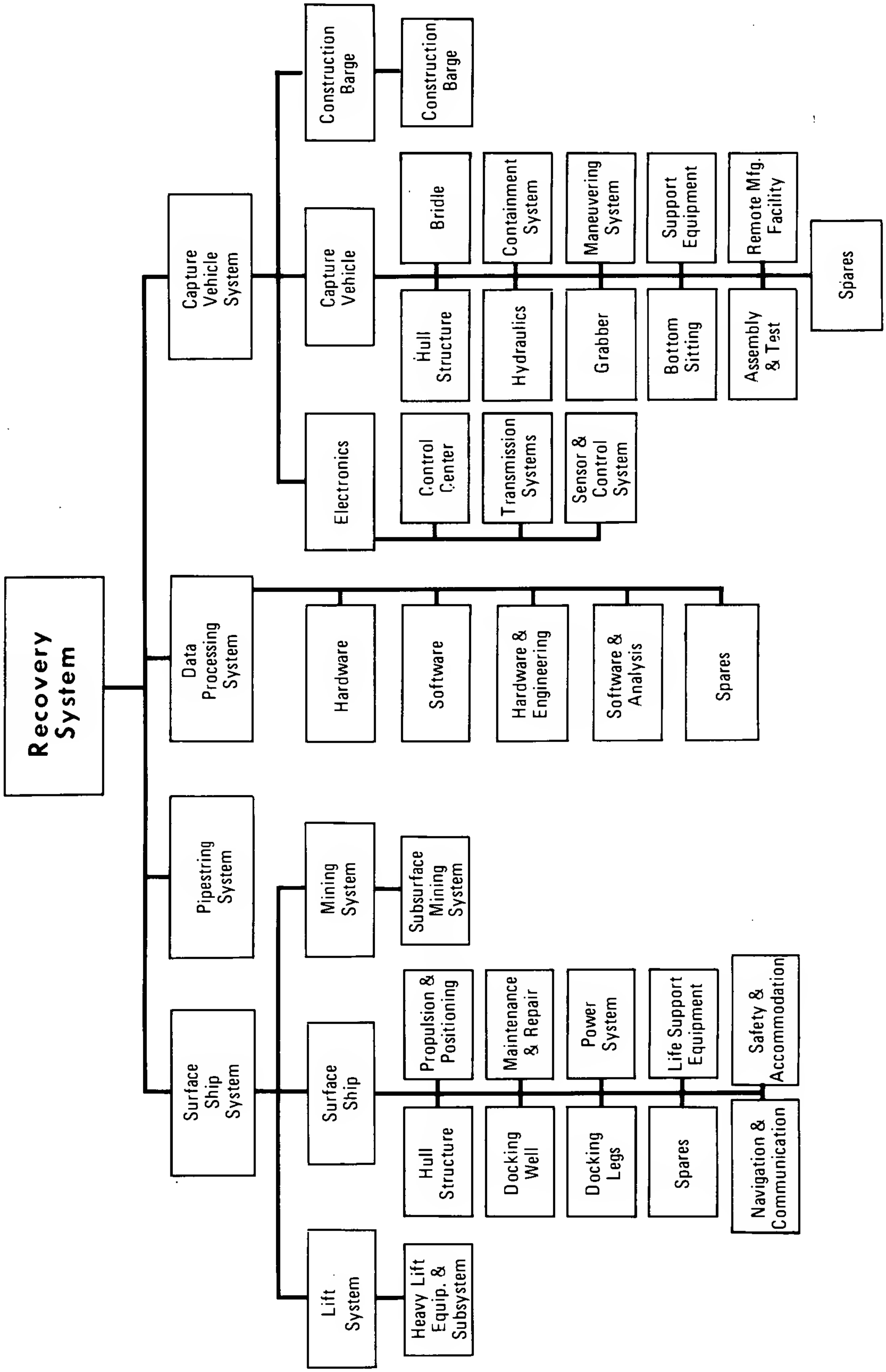
It took a high order of vision and courage for the program managers and engineers to go with the concurrent design/construction philosophy. They recognized that it would mean changes and cost increases from the baseline of October 1970, and that they could incur ex post facto criticism of their decision. But they made the decision, they stuck to it, and it proved vital to the program. Without it, the project might have died in birth or incurred costs far in excess of what they turned out to be.

Engineering Organization

The interwoven and potentially chaotic engineering responsibilities for design and construction were managed by a four-level planning structure (see Chart). The highest level (0) was the over-all recovery system, the totality of the hardware. The next level (1) contained the four principal hardware systems and contractors, which were the surface ship system (Global Marine), (b)(1) [redacted] the pipe string system (Summa/Hughes Tool Co.), and the data processing system (Honeywell). These were broken down into their major components for the next lower level (2). For example (b)(1) [redacted] Finally the lowest level (3) to be controlled by CIA project engineers contained the major components of Level 2. Obviously, the levels could go on *ad infinitum*, but it was concluded that major decisions would not go below Level 3; therefore, the lower levels were supervised by contractor engineers under the direction of Agency engineers.

Project AZORIAN was managed by the Special Projects Staff (SPS) of CIA's Directorate of Science & Technology. Within SPS the engineering group was headed by (b)(3)(c) [redacted] His deputy was Dave Sharp, who later took part in the mission as Deputy for Recovery (b)(3)(c) [redacted] staff comprised only seven additional engineers, an incredibly small number to manage this complex and costly system. Needless to say, each of them was "a rambling wreck and a helluva engineer."

AZORIAN SYSTEM PLANNING STRUCTURE



The Surface Ship

The *Hughes Glomar Explorer*, or as it come to be known, the HGE, was created from the vision in one man's mind. John Graham of Global Marine was the chief designer and supervisor of construction. It was the culmination of his career as a naval architect. For anyone who had anything to do with the design and construction of the HGE, John was the hub around which all engineering activity took place. A man who was often frustrating to work with, he was nevertheless single-minded in his efforts to construct a ship that would do a salvage job heretofore believed impossible.

a. Requirements

Stated simply, the requirement on the surface ship system (the HGE) was to pick up 3,920,000 pounds (1750 tons or the equivalent of a World War II light destroyer) from the ocean floor, lift it over 3 miles to the surface, and place it within the bowels of the ship. [redacted] (b)(1) [redacted] All this was to be done covertly. The HGE had to provide space [redacted] (b)(1) [redacted] It also had to provide berthing for the (b)(1) [redacted] crew for up to 100 days at sea.

These general requirements were translated into detail lists of very specific design requirements for each of the lower system levels. To give some flavor of what these requirements were like, two examples are presented:

Ship Underway

Sea State	Storm conditions with significant wave height of 103 feet
Wind Velocity	100 knots
Temperature	40-105°F
Pitch	15°
Roll	60°

Static Hold (Fail/Safe While Lifting Target)

Sea State	12 foot sea, 18 foot swell
Wind Velocity	50 knots
Temperature	40-105°
Pitch	15°
Roll	22°
Heave	32 Feet
Drill Floor	
Gimbal Pitch	10°
Gimbal Roll	17°
Heave Compensator	14 Feet Working
Dead Load	17,750,000 Lbs.
Live Load	19,750,000 Lbs.
Overload (Max.)	29,800,000 Lbs.

Lists similar to these two examples were compiled for each of the sub-systems which, in total, comprised the surface ship system. Besides being interwoven among themselves, these requirements were also tied into all the other requirements of the other Level 1 systems.

b. Construction of the HGE

During the spring of 1970 contractors were being selected to design and build the major elements of the HGE. Global Marine, because of its experience as a ship designer and fleet operator in offshore and deep ocean activities, was selected to design and build the HGE with a subcontract to Sun Shipbuilding and Drydock Co. The initial visual assessment of the Sun Shipyard in Chester, Pa., was made from a Metroliner as it rumbled close by enroute to Philadelphia. The lift system was done by Global Marine with a subcontract to Western Gear. Global Marine also became the total system integrator. The success of the *Glomar Challenger* was another factor favoring the selection of Global Marine. They had designed, built and operated this ship for the National Science Foundation. She had an outstanding record of service and had been a huge scientific success.

By mid-1970, with the heavy lift systems concept defined, total system design was initiated. The concurrent design/construction philosophy required continual compatibility assurance among all the elements and extremely accurate initial design weight estimates. Rigid weight budgets were placed on the massive machinery of the lift system. Equipment was being sized relative to the estimated weights of the target, the capture vehicle, and the 16,700 feet of drill pipe. Any erroneous estimate resulting in a major hardware overweight could stall the lift system, which would not be tested under full load until the mission. As it was, and in spite of some increases and some decreases, the system element weight estimates proved accurate in terms of the total lift. The estimated weight of the target proved conservative.

Although system design continued into late 1971 with the publication of the major element specifications, a few long lead-time items were ordered starting in November 1970. Major long lead-time procurement began in March 1971. This included materials (steel) for the ship hull, ship center well, A-frame, gimbal platforms, gimbal bearings, and the 5-foot-diameter by 20-foot-long heave compensation and heavy lift system cylinders. These latter items required from 15 to 18 months lead time and were needed for installation in the fall of 1972.

One problem incurred in the procurement cycle was the "Buy American" policy. A very few small items [redacted] (b)(1) were available only from a sole source. Two major procurements were a more severe problem and required the appropriate permission to buy foreign. [redacted] (b)(1) Adding spice to the latter case was the delivery of the cylinders [redacted] (b)(1) by a Communist bloc freighter.

The major elements of the system were already undergoing bid evaluation and vendor selection during late 1970 and early 1971. By July 1971 improvement in the target object definition led to some major specification changes. Measurement of the effective horizontal distance from the keel to the top of the sail of the target was increased by several feet [redacted] (b)(1) This required widening the center well of the ship from its 69-foot width to 74 feet. This, for geometric, structural and stability reasons, increased the beam from 106 to 116 feet (now making passage through the Panama Canal impossible). The ship's length was also increased to 589′-7″ at waterline or 618′-8″ overall. These dimensional changes were driven as much by stability requirements as by geometric and structural considerations. Without them, the ship's self-righting capability when it rolled in heavy seas under worst-case loading conditions would be marginal. Worst-case loading would occur at the beginning of target recovery after the target had been freed from the bottom, with the combined total load estimated at 16,300,000 lbs. hanging off the gimbal platform 100 feet above

the waterline. Anti-roll tanks also were incorporated in the ship's design to further improve stability in heavy seas.

By late 1971 work on hardware for all the major elements of the ship system had started at the same time the engineering specifications were being completed. The ship's keel was laid on 16 November. Final designs were frozen after confirmation and re-confirmation through simulation, analysis, and model testing.

The builders of the heavy lift system were well into testing components and systems during the spring and summer of 1972. When one of the lifting yokes failed under a proof load, metallurgical and structural investigation of the failure dictated a change from the T-1 steel specified by the designers to the more forgiving HY-100 steel. The tests surfaced this problem in time for two new HY-100 yokes to be built and delivered to the ship for installation without seriously disrupting the schedule.

Other major equipment was arriving at the Sun Shipyard by fall 1972 for installation as the hull neared completion. On 4 November 1972 the ship was launched, installed briefly in drydock to have its false bottom removed and the well gates installed, then tied dockside for resumption of equipment installation. Figures 3 through 10 depict construction activities during this period.

The intense activity at the Chester, Pa. shipyard and the pace of related construction programs were reviewed weekly by managers meeting in nearby Philadelphia, where they charted current progress, determined what corrections were

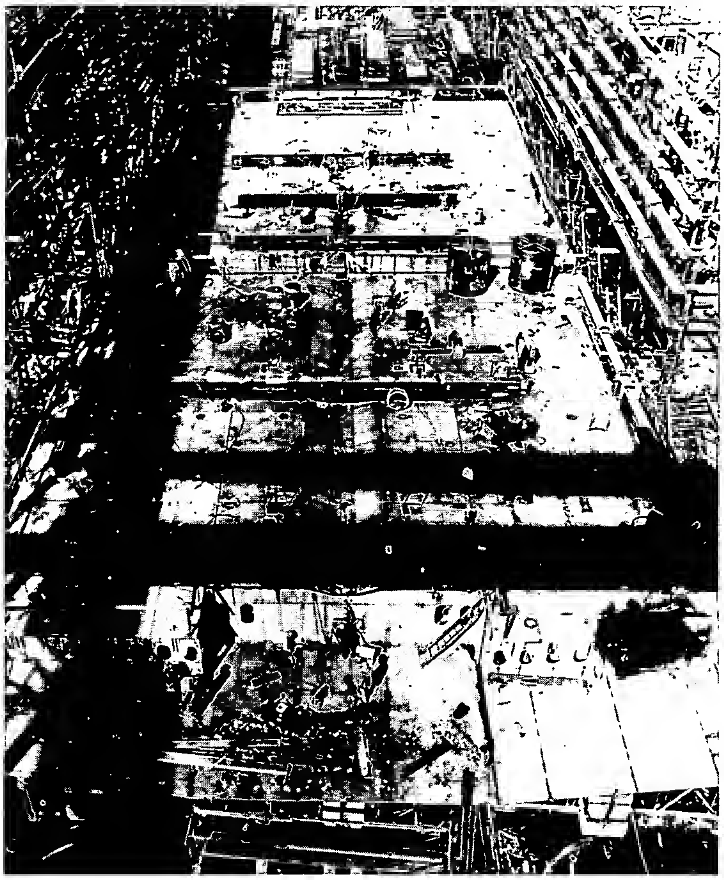


Figure 3. The first stage of construction—laying down the docking well gates

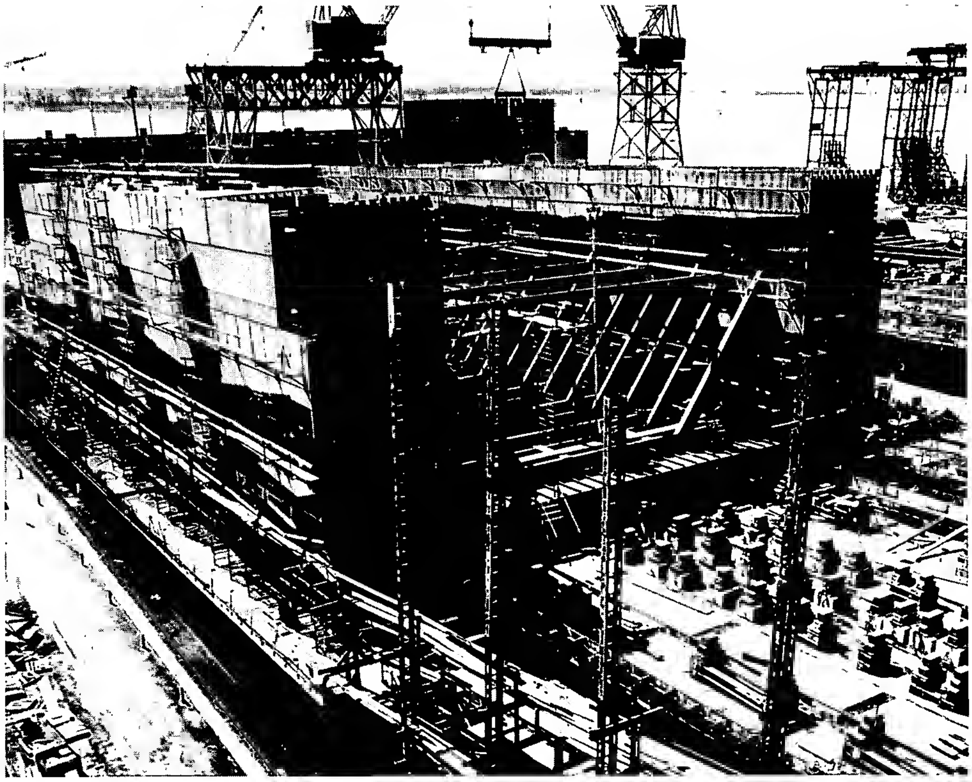


Figure 4. Wing walls going up from the gates and forming the sides of the docking well

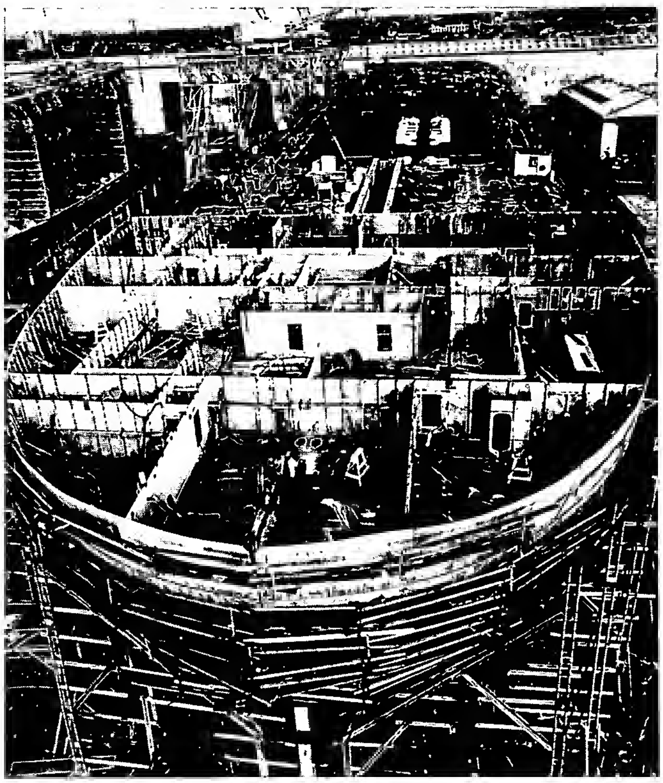


Figure 5. Interior construction looking forword from the stern

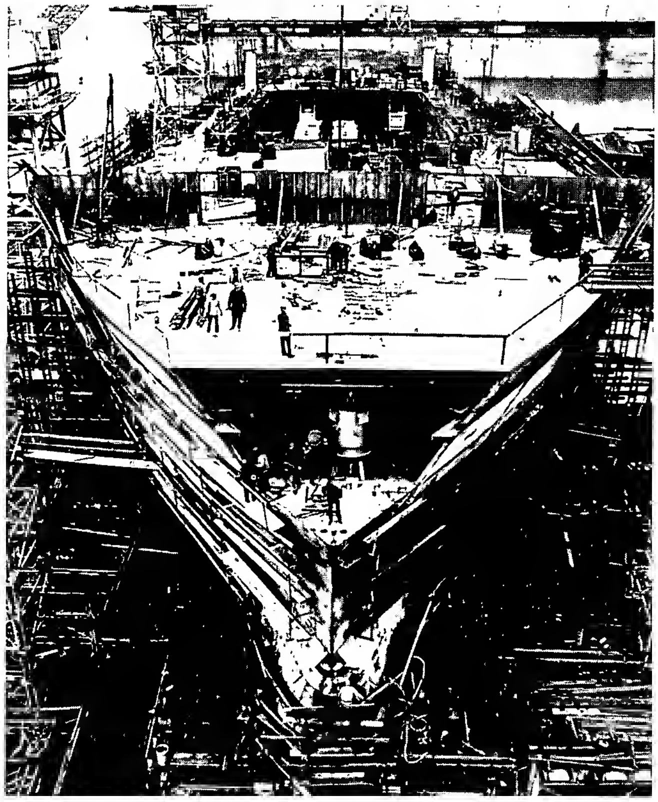


Figure 6. The bow in final stages of construction

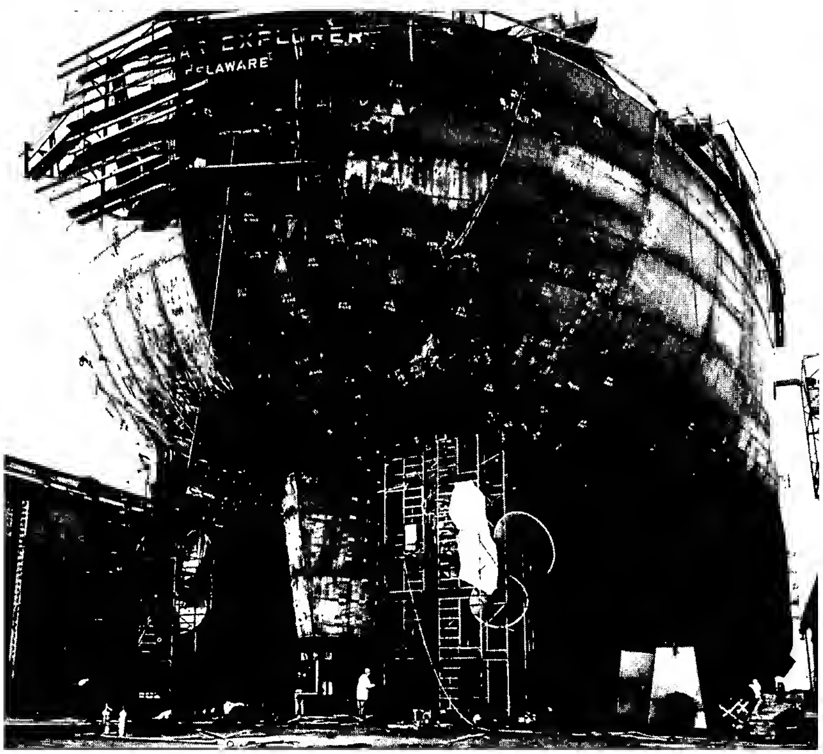


Figure 7. A view of the stern showing the twin propellers

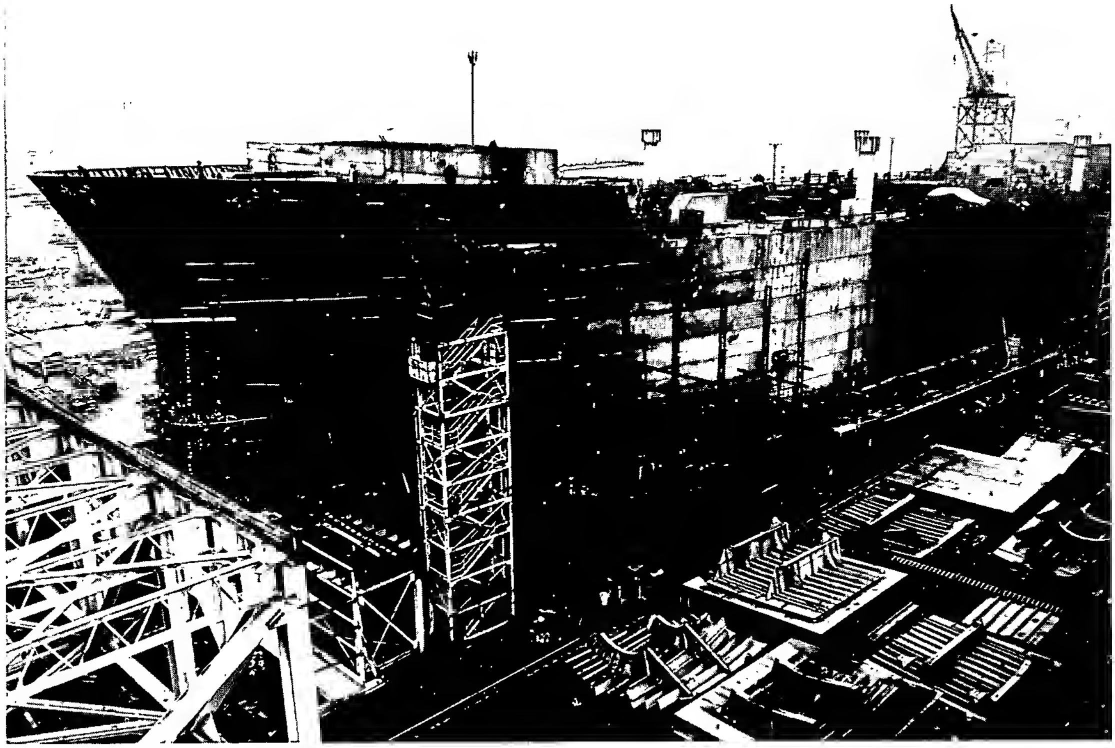


Figure 8. Final hull work including painting

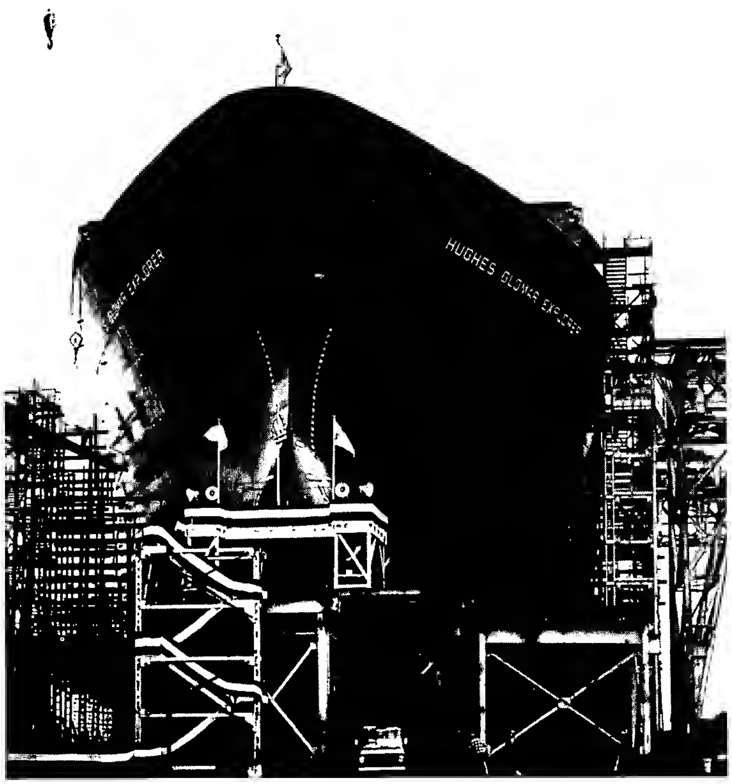


Figure 9. Almost ready for the launching ceremony

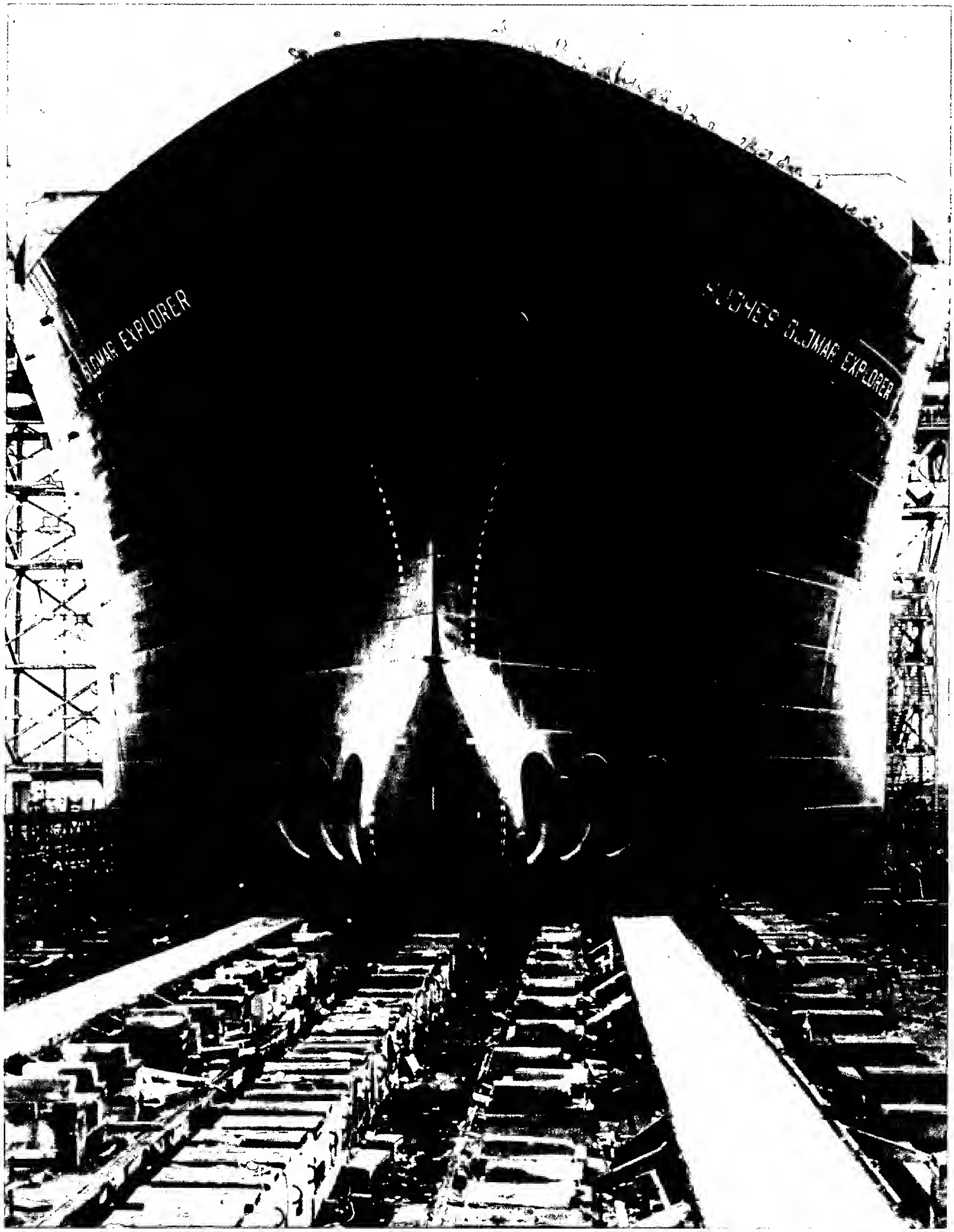


Figure 10. Sliding down the ways

necessary, and passed these on to all program managers. After each session, detailed scheduling meetings would be held the next day at the shipyard to focus on the progress and problems of the HGE.

By January 1973 the HGE engines were running and shore power was disconnected. The 800 tons of gimbal platforms and bearings, which had been concurrently pre-assembled pierside, were installed on top of the shipboard heave compensation cylinders with the Sun 800 barge crane (Figures 11 thru 14). The Sun 800, specially constructed by Sun for this lift, was the largest capacity (800 tons) barge crane on the East Coast (Figure 15). Later, because the ship's derrick was too tall to pass under the Delaware Memorial Bridge, this crane followed the HGE downriver to set the derrick aboard after the ship had cleared the bridge.

It was a busy time and the headquarters engineering representatives found themselves more often at the shipyard than anywhere else. The magnitude and complexity of the installations were greater than the initial shipyard estimates—more manpower and more time were being consumed. Continued meetings were held with shipyard management in an effort to keep electricians, pipe fitters, mechanics, welders, and their foremen working on board the HGE in the face of stiff competition from other ships also under construction. It required the clearance and briefing of a Sun Shipyard vice president (he was also the production manager) to improve the situation.

During February and March 1973, installation of major recovery system component plumbing, wiring, and lift system control equipment continued. The

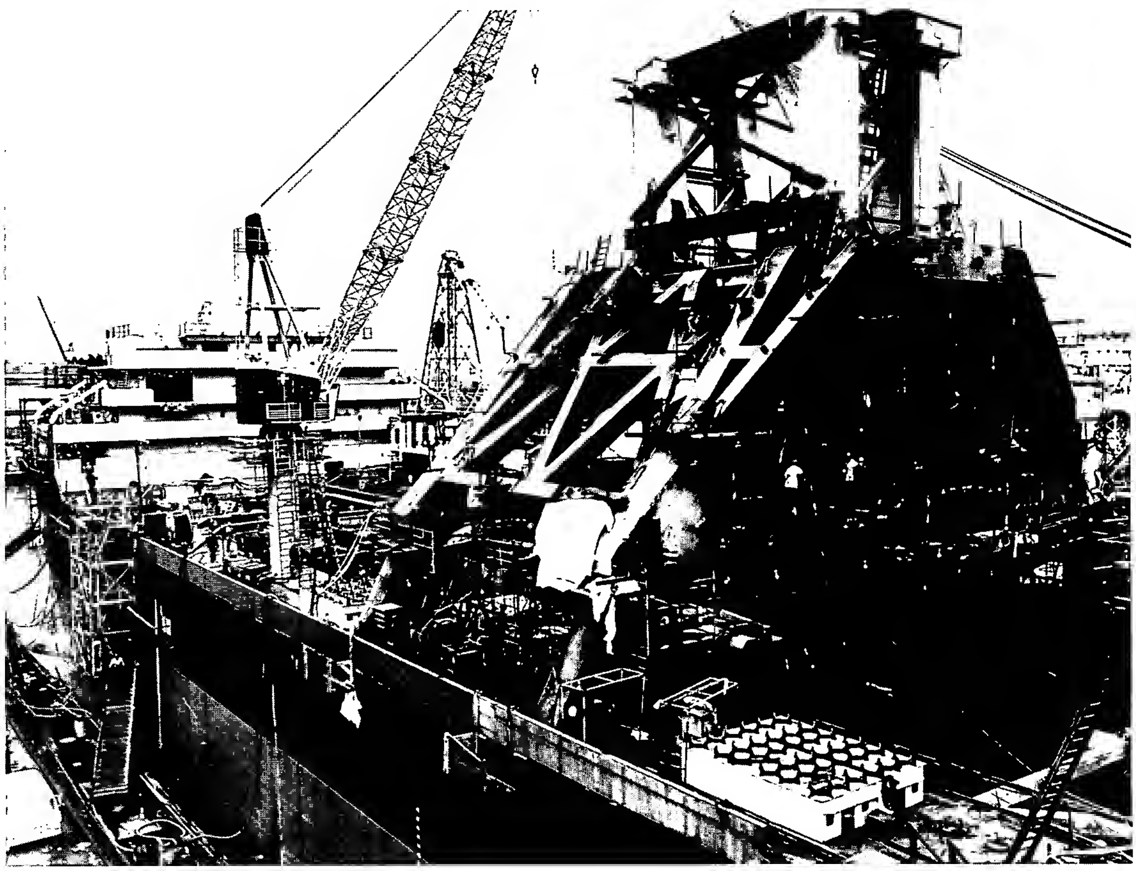


Figure 11. A-frame structure which provided the load path from the lift system to the ship

Figure 12. Aft heave compensator cylinder. This is one of the shock absorbers which removed the up-and-down motion of the ship from the recovery mechanism.

Figure 13. Inner and outer gimbals which removed the roll and pitch motion

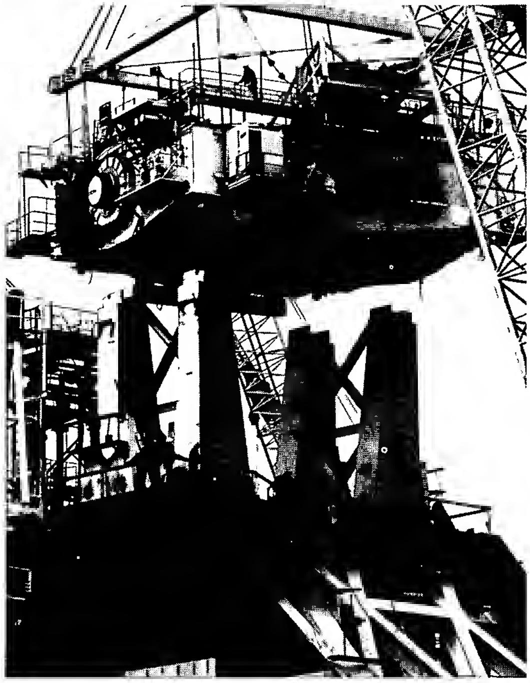


Figure 14. Gimbals being set on the A-frame

docking legs were installed and welded. The rig floor had been installed and was receiving equipment for the draw works. Coast Guard representatives were following all activities. Tie-down castings were installed in the well floor. These would later be changed to weldments* because the porous castings absorbed leakage from well-gate ballast. The balance of shipyard effort was devoted to dock trials of basic ship's systems in preparation for the builder's sea trials on 12 April.

The period after builder's trials (which were successful in demonstrating the intended basic ship's systems) from mid-April to 24 July 1973 marked the completion of the recovery system installation and the initiation of its dock trials. After extensive hydro-testing to 4500 pounds per square inch and rework, the heave compensation system held pressure. The piston rods with their yokes supporting the 800 tons of gimbal platforms and lift system finally made the 15-foot trip up the guides from full low to full high position and back down again, The heave compensation system had completed dockside checkout.

Like the heave compensation system, the heavy lift system required several cycles of hydro-testing, repair, and retest before the system held pressure. The flanged joints were a particular concern. Their surfaces had to be perfectly machined and aligned in order to hold the proof test pressure of 4500 psi. After considerable rework, this system held pressure and was ready for final dockside test. Finally both sets of the lift cylinders with their rods and yokes were stroked 15 feet, but not without damage to the upper yoke. An out-of-synch condition between the two piston rods caused the yoke to tilt and bear against one of the rods. Metallurgical and structural assessment showed the damage was repairable and the yoke stiffener plate was repaired in place.

With completion of the stroking, the lift system testing had progressed as far as was feasible while the HGE was still dockside. Little shipyard testing was done on the pipe handling system because of the intensive shipyard activity on other systems. In

* Weldment: structure formed by welding individual pieces of steel into a desired shape—Editor.

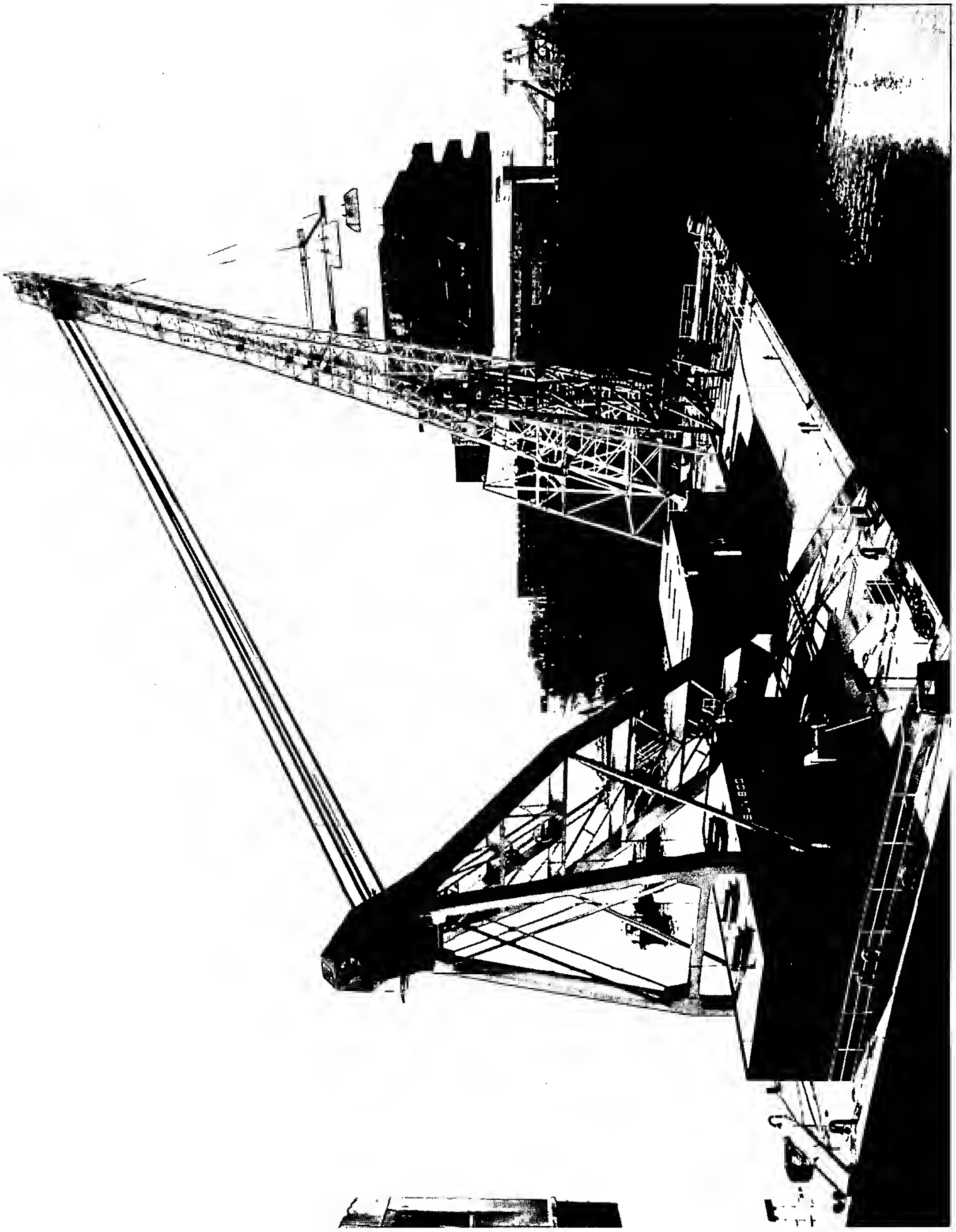


Figure 15. The barge crane, Sun 800, lifting on the prefabricated aft deck house

fact, there was nothing more at all that could be done in the yard, and the HGE departed the Sun Shipyard on 24 July 1973 for further sea trials (Figure 16). Construction of this remarkable ship had been completed in the equally remarkable time of 20 months after laying of the keel.

The story of the construction of the HGE would not be complete without skipping ahead 15 months to October 1974 and the preparations for the follow-on mission code-named MATADOR. AZORIAN had tested fully the basic design of the surface ship system. Although the equipment gave us many problems during the recovery mission, nothing had faulted the soundness of the basic design. What was needed were repair of damaged hardware and engineering improvements—fine tuning of the major sub-systems, if you will—in order to make the over-all operation more smooth and trouble-free. This was especially true in the heavy lift system and to a much lesser degree in the pipe handling system. The HGE itself had come through with flying colors. All that she required was a facelift—cleaning and painting the hull—after a thorough non-destructive inspection and minor repairs. The MATADOR test operations were very successful and proved the value of the modifications.

c. HGE Technology and Cost

The HGE and its associated sub-systems created a number of significant technical achievements and breakthroughs. The ship was the first one to be designed and analyzed using finite element analysis (approved by the American Bureau of Shipping). It had the largest (199 feet by 74 feet) center well with movable gates. The 24,500 horsepower diesel electric marine power system was the largest built that used 4100-volt alternating current coupled to silicone-controlled rectifiers. The use of jack-up type legs, derived from the offshore oil industry, as the docking mechanism solved the problem of mating two massive bodies in a seaway and was an important breakthrough.

The heavy lift system was the largest and most powerful (8000 tons) lift system ever built. The pipe handling system was the largest automatic one in use and could store and assemble 60-foot pipe sections averaging about 15 tons each. The heave compensator and gimbal platform were the largest in the offshore industry. They supported 10,000 tons and isolated them hydraulically and pneumatically from ship motion. This in turn permitted precise bottom operations to be carried out with highly accurate positioning while the surface ship was responding to wave and wind forces.

The cost (in millions) of the surface ship system were:

basic ship	(b)(1)
heavy lift	
docking legs	
spares	
Total	

The World's Largest Submersible

The *Hughes Mining Barge-1*, known as the HMB-1, was and still is the world's largest submersible. During its construction in San Diego, President Nixon was photographed in front of it giving a speech about U.S. Government support to the American shipbuilding industry. Presidential publicity for the HMB-1 was not a planned part of the cover program, and the Agency received only 24 hours notice of the visit. Fortunately, no undue attention on AZORIAN resulted from the photograph and speech, which were featured in many newspapers.

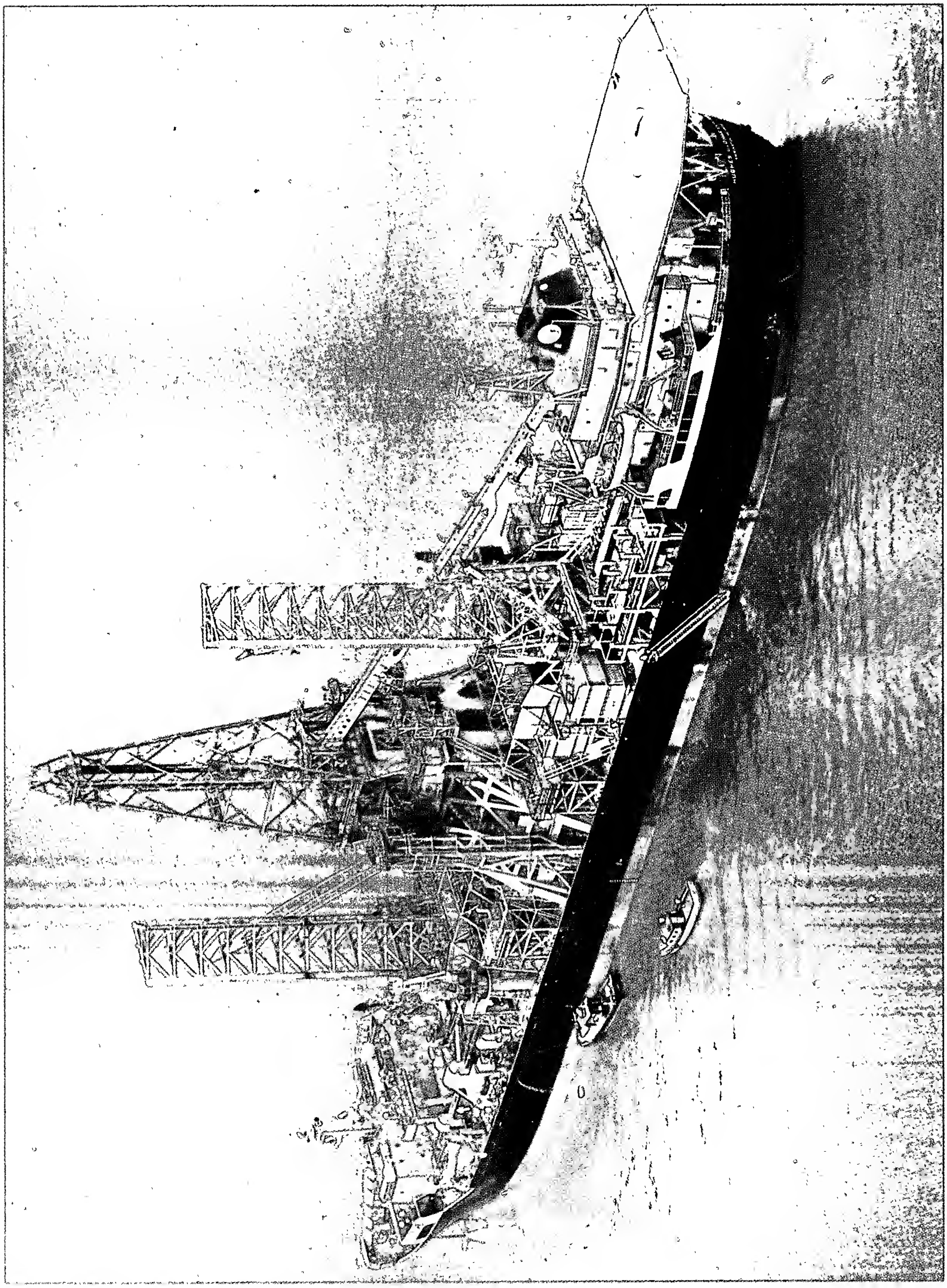


Figure 16. The final product

a. **Requirements**

The HMB-1 had to meet three main requirements. First, it was to serve as the facility for the covert construction of the capture vehicle (CV). The CV was so large it could not be built in the well of the HGE. Even if it could have been, management could not wait until the HGE was completed to begin construction of the CV because the schedules were so tight. Since any public exposure of the CV would blow the mining cover, it had to be built beyond the reach of the prying eyes of news reporters; the construction facility had to be enclosed and protected. Second, because the CV and the HGE were built in separate facilities, the CV would need to be transported to a mating site; so the enclosed construction site had to be movable. Third, a covert method of transferring the CV into the HGE was needed; the construction facility, therefore, had to be submersible to a depth at which the HGE could moor over it and extract the CV, concealed by the intervening water. In any case, the HGE itself was the only device powerful enough to lift the CV's weight of 1600 tons (wet).

b. **Construction**

Building a barge is normally a straightforward process involving uncomplicated structures. A barge is a floating box, and the HMB-1, when surfaced, was not overly complex. But it had to be submersible. Hard and soft tanks were needed for flooding in order to change the bouyancy of the submersible barge. (Hard tanks are built to withstand external pressure; soft tanks are pressure-equalized.) Floodable stabilizing cylinders also were added to control diving and surfacing operations.

(b)(1) developed the design, construction plans, and specifications under contract to Lockheed, the prime contractor (b)(1) previously had designed a partially submersible barge called FLIP. (b)(1) was selected to do the working drawings, construction, and builder's trials.

(b)(1) began fabrication on 11 May 1971 with the laying down of the stern soft tanks. Construction progressed from stern to bow and keel to roof in several planned stages (Figure 17). The submersible complexities did not hinder the construction process, and it went ahead rapidly. Lockheed completed the movable roof design and moved their engineers (b)(1) to prepare the test procedures for dock and sea trials. The last structural items, the bow, roof sections, and stabilizing tanks, were completed by early April 1972. On the 14th of April the hull was launched and placed at the outfitting dock (Figures 18 and 19). Here the roof sections and stabilizing cylinders were added. On-board outfitting of the control rooms, roof drives, anchor windlasses, instrumentation and aft bulkhead was completed within a week. The HMB-1 was ready to prove itself as the world's largest submersible.

Sites had been surveyed for the sea trials. Requirements were a smooth and sandy bottom, a gradual slope (less than three degrees), and sufficient water depth for progressive testing to about 185 feet. Two sites were chosen. The first was off Coronado Island in San Diego. The water depth was 55 feet, which meant that the crew, procedures, and barge could be tested without full submergence, and it was close to (b)(1) in case problems were uncovered. The second site was Isthmus Cove on Catalina Island. Here there was sufficient water depth to check the barge at 125 feet, 165 feet and 182 feet.

On 20 April 1972, 11 months after construction began, the HMB-1 headed for its first dive off Coronado Island. After the anchors and buoys were set and all pre-dive checkouts were made, HMB-1 started down (Figure 20). By late evening it was nestled on the bottom. No major problems were found, and the next morning it surfaced. The

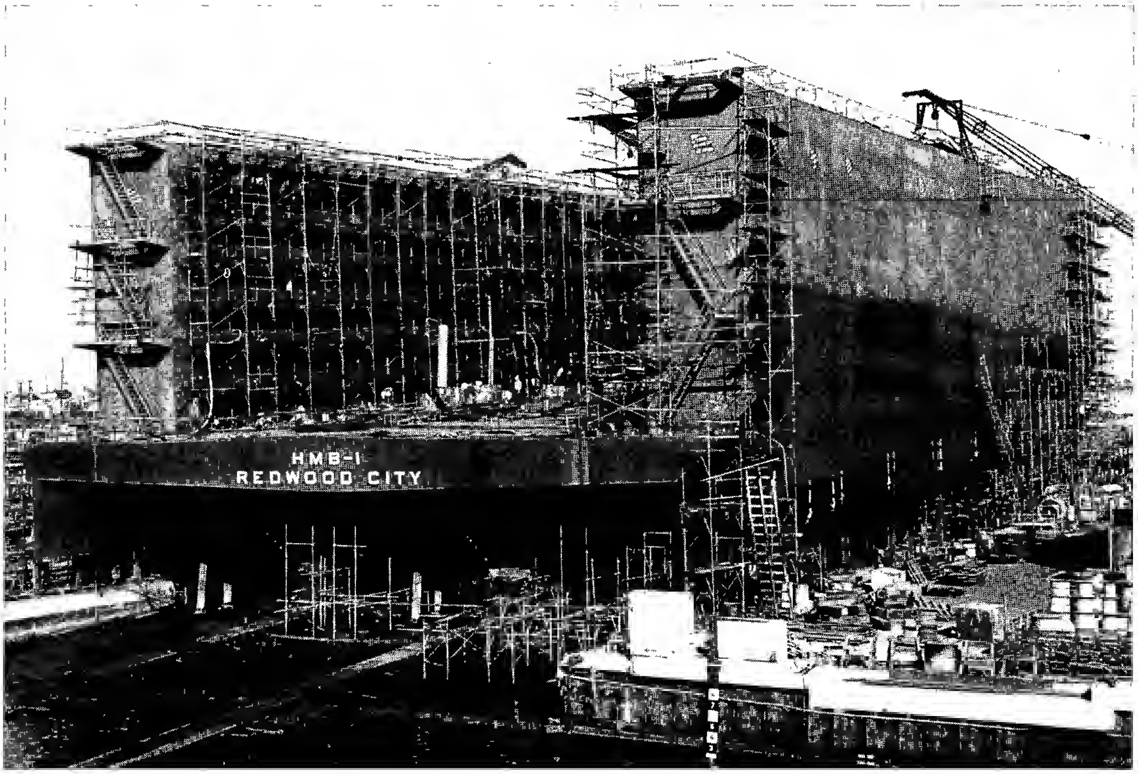


Figure 17. HMB-1 on the ways (b)(1)

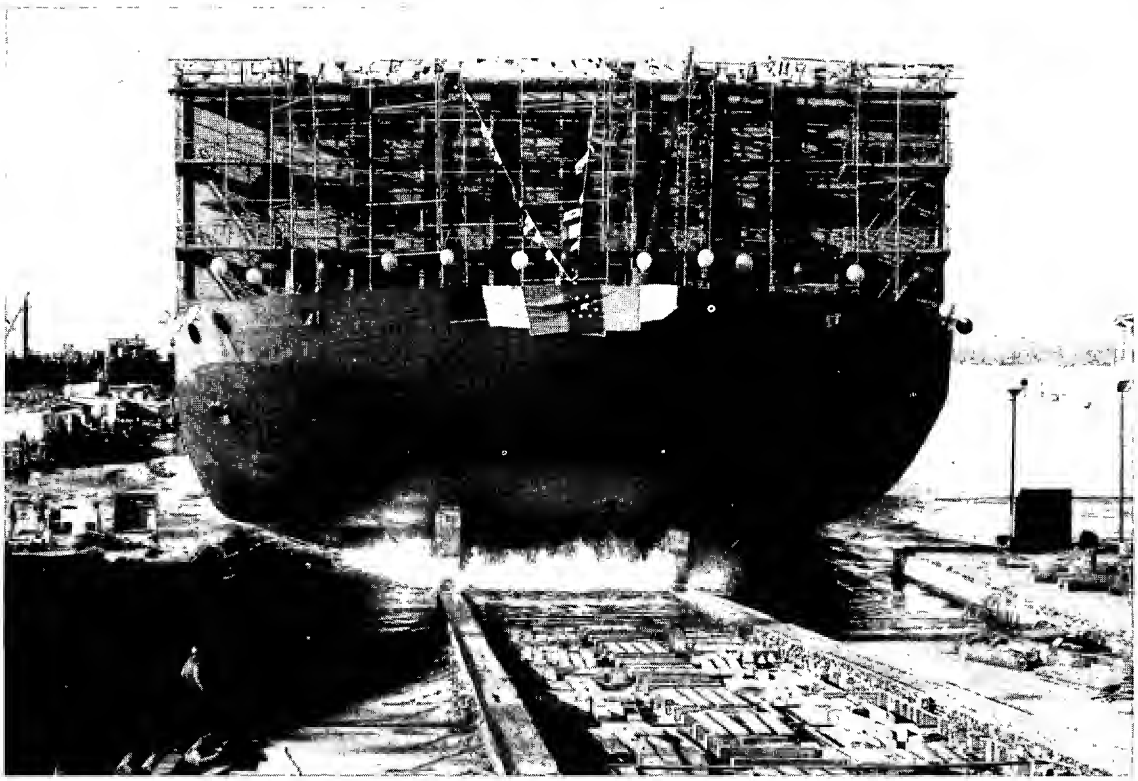


Figure 18. She floats!

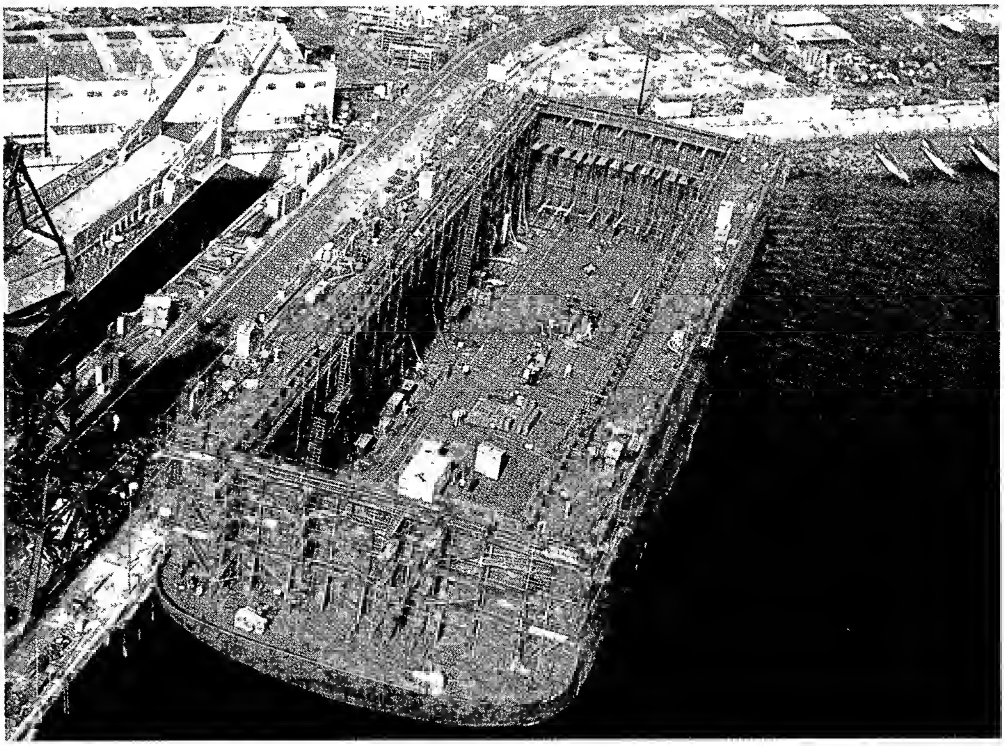


Figure 19. HMB-1 being outfitted at the dock

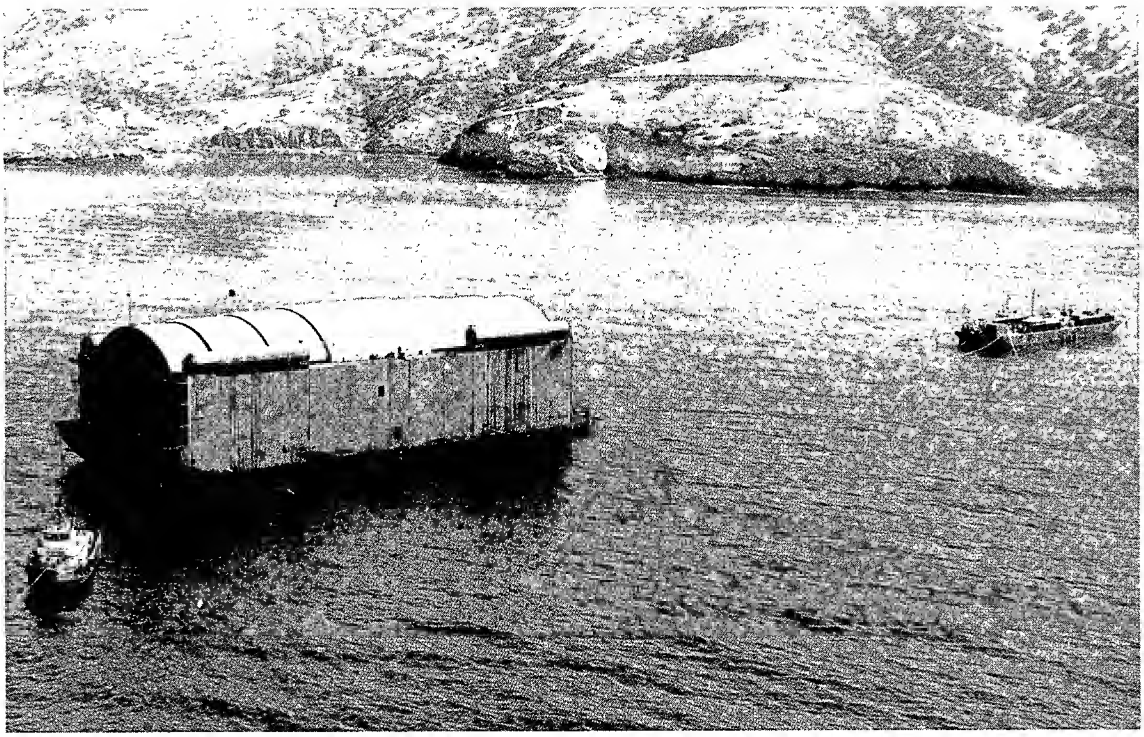


Figure 20. Getting ready for a dive at Catalina. The support barge is at the right; tow boat on left.

following day, 22 April, the tow to Catalina Island began. By 24 April the small test flotilla was anchored in place and ready to begin a series of four dives—twice to 125 feet, once to 165 feet, and a final dive to 182 feet.

The dives were conducted between 24 April and 10 May. On the first dive, air remaining in the barge collected under the roof as it descended; almost as quickly as it went down, the HMB-1 rose to the surface. As the air vented through holes in the roof, negative buoyancy returned and it dropped to the bottom. This yo-yo effect was overcome in subsequent dives by blowing the ballast tanks to insure that the HMB-1 remained negatively buoyant throughout the dive sequence.

There were minor, correctable problems with the next two dives, but on the fourth dive a really tough one appeared when a float valve in the starboard control room closed, shutting down the constant air supply essential to the operation of the barge's instruments, including the valve controls by which buoyancy was regulated. The HMB-1 lay dead at the bottom, unable to respond, until divers were sent down and into the control room to operate the valves by hand. The diving sequence proceeded to a successful completion without incident or damage to the barge. The problem was quickly identified: the float valve had reacted to excessive moisture in the compressed air, "identifying" it as water and dutifully closing down. A design correction erased the problem and on 10 May the HMB-1 cleared the test site for Redwood City on San Francisco Bay, where it would become the construction hanger for the capture vehicle.

c. HMB-1 Technology and Cost

The HMB-1 contributed its own technical achievements to the AZORIAN program. It was the world's largest submersible in addition to being the construction facility, transport vehicle and covert transfer mechanism for the 2400-ton (dry) capture vehicle. Another technical accomplishment was the unmanned submergence of this huge barge. A floating vessel goes from positive buoyancy through zero buoyancy to negative buoyancy during the submerging process. At zero buoyancy the vessel is unstable and theoretically could go belly-up at this moment. It was no small achievement for the HMB-1 to go through this critical instability point while unmanned.

The barge was built in 11 months at a cost of (b)(1) After completion of the test dives it was towed to the Redwood City facility which was to be home base. There, on 30 May 1972 the assembly of the capture vehicle began in total secrecy.

My Darling Clementine

The one piece of equipment that couldn't bear public scrutiny was the capture vehicle. Its giant arms with davits (forearms) and beams (upper arms) could serve only one purpose—encircling something huge. They deserved their name, the Grabber System. Although the CV was christened Clementine, no one would ever believe that she was ever remotely related to the Miner and Forty-Niner immortalized in song. The design, therefore, had to be done in secret, as did the assembly. Any failure here would end the cover and the mission. To give credence to all the security precautions taken, Clementine was billed as Howard Hughes' latest engineering marvel. She was the key to making him even richer by efficiently harvesting the manganese nodules lying on the ocean floor. No one was to see Mr. Hughes' new device. The story was floated, believed, and served as the perfect cover. No unauthorized individual ever saw Clementine, not in her boudoir, not in her drawing room, nor as she went about her calling.

"The Claw is in the Bay" was the headline splashed across the front page of a local newspaper when the HMB-1 first appeared in the San Francisco Bay area. What a surprise it must have been to the writers when they found out how close their headline actually was; not to the Claw, the local nickname for Howard Hughes, but to a not so dainty lady named Clementine.

a. **Requirements**

The CV, like the HGE, had detailed lists of design requirements for each of its major elements as well as all of its many subsystems. Strength requirements for the various load-carrying structures were defined, total system weights were carefully estimated since the lift-off weight was a critical factor in mission success, and controls for setting the massive CV down on the target were exactingly specified to achieve an accuracy of placement within one foot. The alignment would involve two massive objects (each the weight of a light destroyer), one of which would be remotely controlled at the end of a flexible pipe string. Analogies to help grasp the complexity of the task are not completely satisfactory. But imagine standing on the top of the Empire State Building with a four by eight-foot grappling device attached to one end of a one-inch-diameter steel rope. The task is to lower the rope and grapple to the street below, snag a compact-sized car full of gold (for weight simulation, not necessarily value) and pull the car back up to the top of the building. And the job has to be done without anyone taking note of it. Mission Impossible?—one might think so.

The structures and mechanisms of the CV had to provide the mechanical features necessary to seize the target on the bottom, free it from the surrounding muck, and hold on to it and lift it to the surface, and place it within the HGE. The same mechanical features also had to have the capability of disposing of the submarine at sea after it had been gutted, analyzed and stripped of its secrets. Other design requirements on the CV system involved sensors and controls which provided the necessary navigation and status information for operational decision-making. Two complex electromechanical cables tied the CV with the control center and were part of the CV system requirement package, as was the control center itself.

The CV arrangements were designed with personnel safety as the prime requirement. Concern for personal safety was high in the designers' minds because of the massive size of the equipment that had to be handled at sea on a rolling and pitching ship. And divers would have to work around the CV during the deployment operation. Next in the designers' priority list came satisfaction of functional requirements, followed by protection from damage, accessibility, minimum complexity and minimum structural foundations. A useful life of three years was the design goal for all components and subsystems. The CV was not to exceed 4,929,000 pounds dry weight or 3,300,000 pounds weight in water and was required to withstand 10 exposures to 16,700 feet and survive for 500 hours of continuous operation at this depth.

b. **Construction**

The prime contractor selected to build the CV system was the Lockheed Missile and Space Company (LMSC). They were selected for three main reasons: their Ocean Systems Division had considerable experience in building submersibles, LMSC had shown good system engineering methodology in their aerospace efforts, and they were long and successfully experienced in running "black" programs. The latter was particularly important because the success of the cover story hinged on keeping the CV in the "black." LMSC had the ability to go to a wide range of subcontractors without letting them in on the true story. For example, the backbone of the CV was

constructed by the U.S. Steel's American Bridge Division in South San Francisco. The steel for the beams and davits was supplied by Allegheny Ludlum in the East; they were fabricated at the Kaiser-Fontana steel works in Southern California. One major subcontractor to LMSC was brought into the black side of the program. Honeywell's Marine System Division in Seattle was given the contract for the electromechanical cable and all the sonars and controls for the CV.

The CV system was broken down into three elements, the CV element, the electronics element, and the construction barge element, the last being the HMB-1 already described. The CV element was the principal structural and mechanical assembly of the CV system. The electronics element provided the CV element with electrical power, sensors, and controls.

Within the CV element, the hull structure served as the primary load-carrying member. Originally it was designed as a truss and girder structure. When this design ran into a problem, a "tiger team" from Kelly Johnson's U-2 skunk works was put together to come up with an alternative. As a result of this effort a much lighter box beam design was put forward and approved. It used a relatively new bridge steel, T-1, with a yield strength of 100,000 pounds per square inch (Figures 21 and 22). This box beam design, called the strongback, turned into the world's largest single weldment structure. Some of the welds required as many as 250 passes to complete. The hull structure contained a 15 by 17-foot opening to allow pipe to be deployed while the CV was carried in the HGE's well. It also was compartmented for ballasting. This meant that the CV could be adjusted 0.6 degree and 2.5 degrees in list and trim, respectively, for docking operations. The hull structure also carried all the sensors, propulsion units, and the electronics spheres and cabling.

Figure 21. Strongback being loaded on the HMB-1 at the Ambridge plant in South San Francisco

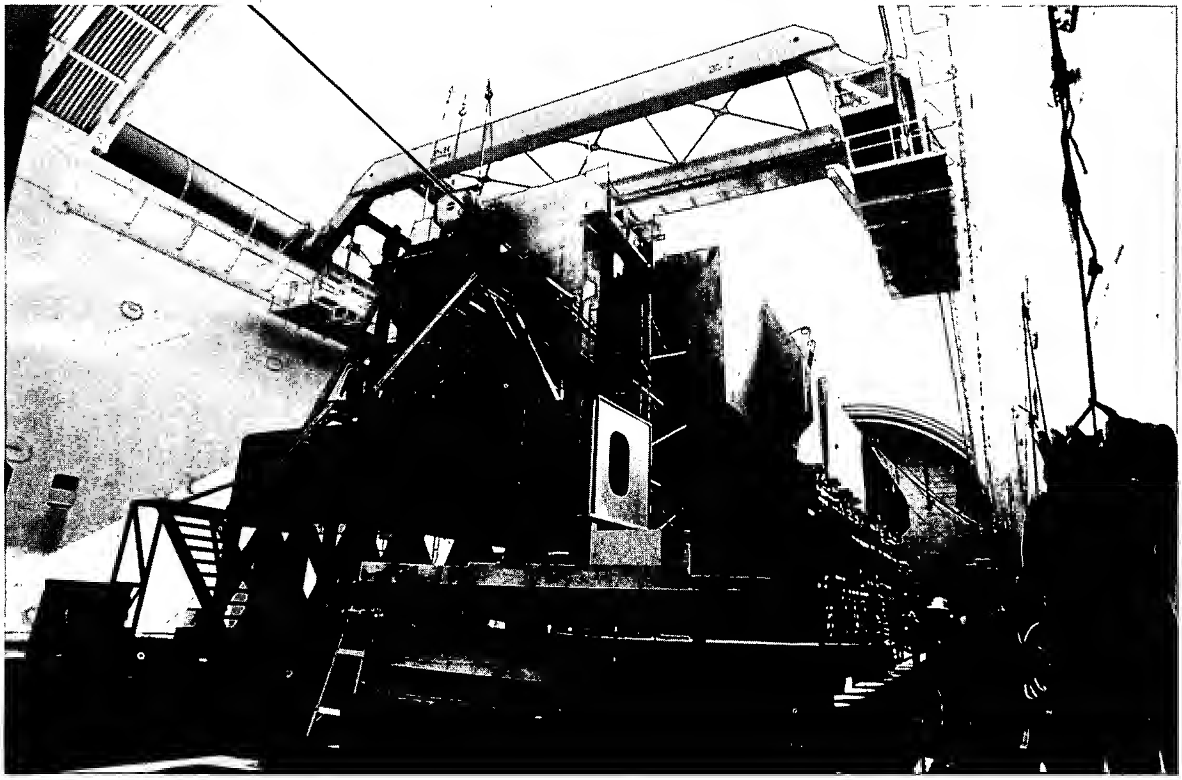


Figure 22. Strongback shored up in the HMB-1 and ready for outfitting

Attached to the hull were the four massive bottom setting legs, 12 feet in diameter with 15 by 16-foot rectangular foot pads (Figure 23). Each leg had an inner cylinder which could be extended 35 feet at a rate of 1.5 feet per minute using hydraulic pressure from sea water pumped down the pipe string. These legs could develop a total lift of 5,740,000 pounds which was to be used to extract the target out of the sticky bottom soil. Once the target was broken out of the bottom, all four legs would be dropped off—their connector pins pulled hydraulically—to reduce the critical lift-off weight.

Also attached to the barge's hull structure were the eight beams and davits (called grabbers) for encircling and holding the submarine hull like a set of gigantic tongs. There were five on the port side and three on the starboard side of the CV. The beams and davits were fabricated from maraging 200, a high nickel steel. This steel had the property of high strength per unit weight of material, which was necessary to keep the over-all weight of the CV within the design goal.* Each grabber had a design load limit of 1,340,000 pounds or about 600 long tons. The safety factor was 1.5—the grabber could take 1.5 times its design load before failing, for a total load capacity of 900 long tons per grabber. In the event that the target object strength or geometry precluded any single grabber from carrying its share of the load, the spacing was designed so that the added load on the adjacent grabber would not reduce the safety factor below 1.15.

Seawater pumped down the center of the lift pipe (maximum rate 1,240 gallons per minute at 3,000 psi above ambient) provided power for the eight large thrusters

* Unfortunately, the nickel gave the maraging 200 steel ductility characteristics which proved to be insufficient during the recovery operation.

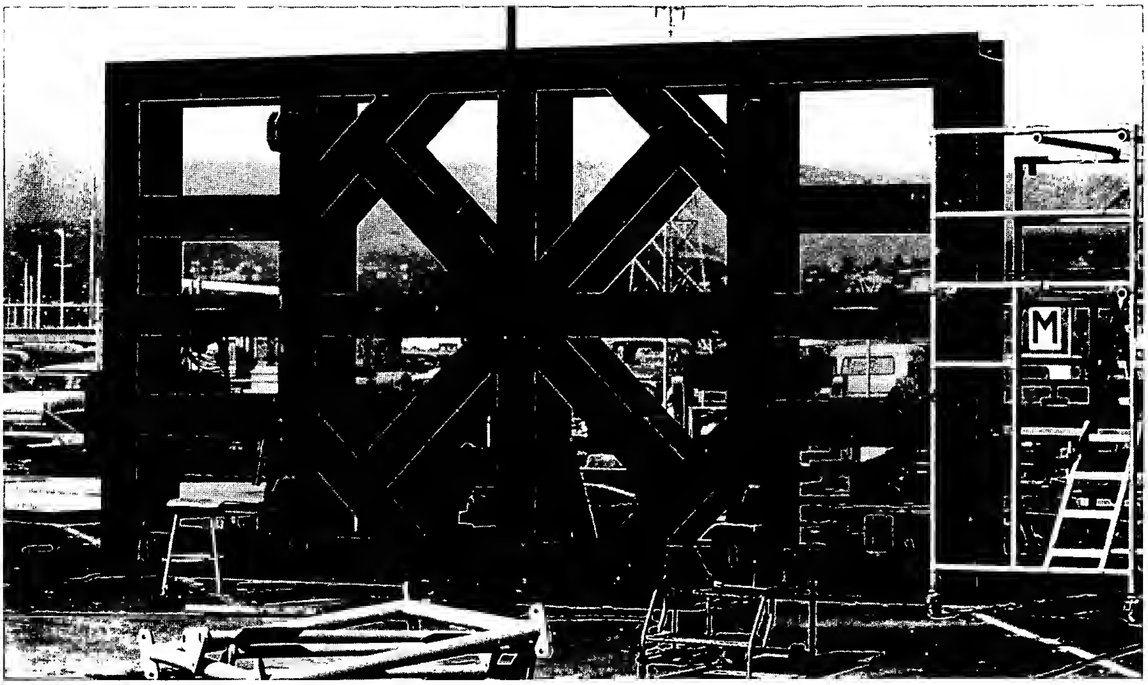


Figure 23. One of Clementine's feet

mounted on the hull of the CV. These thrusters plus two small electrically driven units provided the forces necessary to maneuver the CV and accurately position it over the target for the delicate set-down operation. The pumped seawater was also used to drape a chain net under and around the No. 1 missile tube on the submarine target. Its purpose was to contain, support and prevent the loss of the almost severed tube and its missile contents during breakout and lift.

The CV was attached to the heavy lift pipe by the bridle assembly. This was made from pieces of the small-diameter heavy lift pipe. The apex assembly (the flexible joint between the bridle and the pipe) was made from maraging 200 steel forgings. These were the largest components ever made from this type of steel. The design load for the bridle itself was 9,460,000 pounds. It was stowed in a collapsed position on the CV hull and erected as the CV was lowered on the docking legs.

The electronics element was the third major portion of the CV system. This element, including its array of sensors, provided control of all electromechanical and hydraulic CV equipment, navigation data for determining position and attitude of the CV, imaging of the target object and the surrounding bottom terrain, and status monitoring of the hydraulic and mechanical equipment. There were long-range sonars, high-resolution sonars, altitude/attitude sonars and 11 TV cameras with 22 lights providing the "eyes" for the CV. Target capture could be achieved with either the acoustic or the optic system independently. A beacon transponder array carried on the CV was also deployed around the target. Interrogation of this array by hydrophones on the CV allowed the CV to be positioned with an accuracy of one foot at a range up to 500 feet from the transponders. Maneuvering controls took data from all the sonars and automatically executed commands to the thrusters, thereby controlling the CV heading within ± five feet in surge and ± two and one-half in sway.

Two fully redundant electromechanical cables comprised the transmission portion of the electronics element. These cables were 18,500 feet in length and were

the first ones manufactured (b)(1) The cables handled ship's power provided at 2000 volts, three phase, and 60 cycles. They also provided up- and down-link telemetry channels, a video data channel and an acoustic sensor data channel. A minimum of 9,600 bits of information per second could be handled. The electrical network was designed in such a way that no single equipment or circuit failure could cause mission abort or failure.

The final portion of the electronics element was the control center. It provided the working space for the Mission Director, the Deputy for Handling, the Deputy for Recovery and one assistant, the CV operator, CV work systems operator, optics equipment operator and two acoustic equipment operators. Each station contained the necessary displays and controls to operate all the CV equipments. Three vans made up this complex, which also served as the focal point for secure communications to the forward pilot house, aft pilot house, heavy lift control center, the divers and the ship's center well.

After the major assembly of the CV was completed, it was given a final dry test at Redwood City. This test was completed by 30 June 1973. Prior to this test exhaustive engineering, evaluation and factory acceptance tests were run on components and subassemblies. The engineering team that was building the CV and would eventually operate it was, for all intents and purposes, in permanent residence at the Redwood City facility. By the time the CV left the San Francisco Bay area for mating with the HGE, the CV was complete except for final rigging of the beams and davits. The full area of the HGE's well was needed for the final readiness activity to prepare Clementine for testing and the recovery operation (Figures 24 and 25).

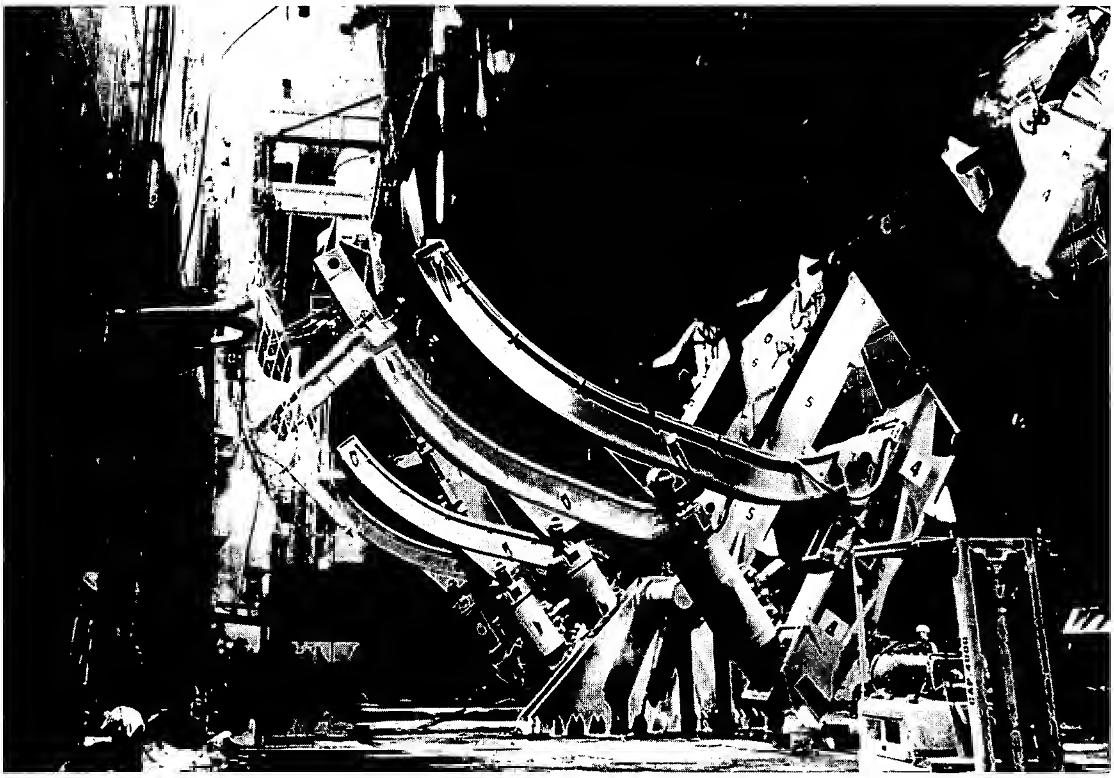


Figure 24. Clementine inside the HGE. Outfitting is almost completed. On the left note the chain net used to contain the missile tube on the Soviet submarine.

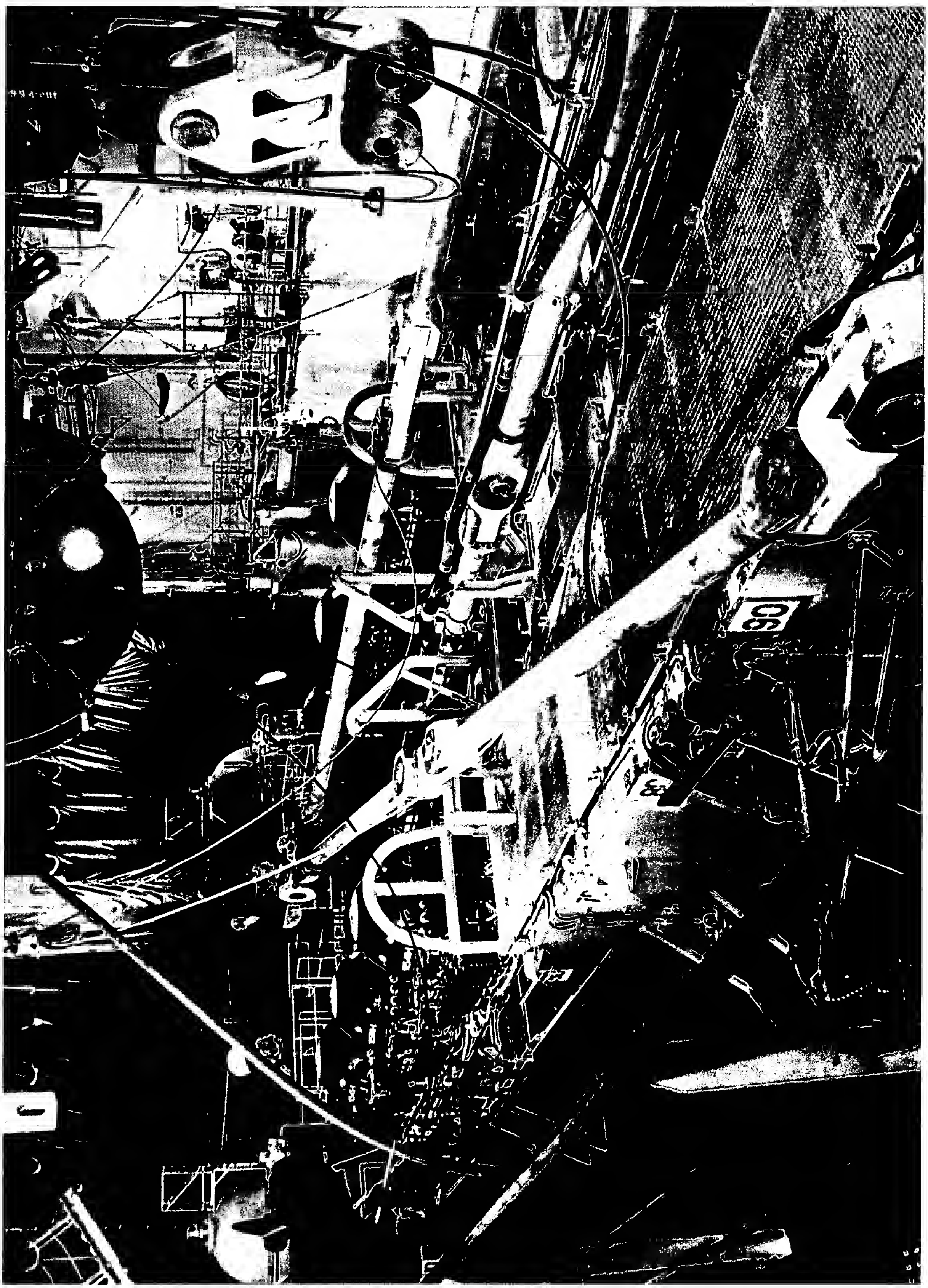


Figure 25. Clementine with her bridle being readied for use

c. Post-Mission Adjustments

After the AZORIAN recovery operation, in which three of the grabber arms failed, the CV design was re-examined in order to determine high stress points in the grabber arms. Four new beams and davits were fabricated from HY-100 steel and one from A-36 steel. This heavier but more forgiving steel could be used now because the remaining target object was smaller, and its weight had been more accurately determined to be less than half the previously estimated weight (1750 tons) of the original target. These facts dispelled the earlier concern that the heavy lift system would be stalled by an excessive load.

Since the breakout legs had been left at the target site, four new legs had to be fabricated for Clementine. The sonar and optic sensors were repositioned to match the new target configuration and pan/tilt controls were added to two TV cameras. All structures were given a thorough non-destructive inspection. After a successful systems test, Clementine was ready for a new attempt, but the second chance was not to be.

d. CV Technology and Cost

The CV system contributed a number of technical achievements in its evolution from design to reality. The electromechanical cable pushed hard against the state-of-the-art in high-strength, long-length, low-diameter, and low-attenuation undersea cables. This cable carried a digital data link used for the first time to control and precisely maneuver a very large machine suspended at the end of flexible drill pipe. The bottom reference system allowed deep operating equipment to be positioned with an unheard-of accuracy of one foot. At the same time, the automatic station-keeping system provided positioning of the large HGE with an error of only ± 15 feet. The CV itself had a hull which was not only the largest structure made from T-1 steel, but also the world's largest single weldment. The deep sea hydraulic legs of about 1000-ton capacity were unique, as was the pressure-compensated electrical system. Finally, the spider and apex block (the flexible top portion of the bridle) were the largest components ever machined from maraging steel forgings.

The CV preliminary design began in mid-1970 and detail design was completed by the end of 1971. Steel acquisition and pre-fabrication efforts started in the first half of 1972. The assembly of the CV began 30 May 1972 and was completed in eight months on 28 January 1973. The dry test was completed 30 June 1973. The over-all cost for the CV was (b)(1) When the HMB-1 costs were added in, the total capture vehicle system costs totaled (b)(1)

Hanging by a Thread

There was clearly a single-point failure mechanism in the approved recovery scheme—the heavy lift pipe. If it failed, not only would the mission end abruptly but major damage would be done to the HGE. The sudden release of energy to the upper portion of the pipe string would create havoc on the drill floor and cause severe injury to the men operating it. The pipe had to be designed with a good safety margin, and it had to be built perfectly. Tight quality control and proof testing would be mandatory. The Hughes Tool Company was selected as the prime contractor for this critical portion of the hardware. It would be almost inconceivable that a Hughes-sponsored mining adventure would not use its own company, Hughes Tool Company, to provide the drill pipe. These pioneers in the oil field and mining supply business had long experience manufacturing drill bits and had a thorough knowledge of pipe machining and metallurgy. Hughes Tool Company was the right combination of technical expertise and cover logic.

a. **Requirements**

The principal requirement on the heavy lift pipe was to provide enough strength to lift the target object and the CV while sustaining its own weight and any dynamic forces added through sea motion. Early CIA studies had concluded that it would not be possible to manufacture a pipe that could meet these strength requirements. Global Marine and Lockheed, after studying the problem, convinced the Agency engineers that the requisite strength could be achieved, but the proof still was in the making. The maximum estimated load on the pipe was 17,126,00 pounds during fail-safe hold conditions.

Other design requirements on the pipe were specially designed screw threads to hold the pipe pieces together. The roots of these threads were highly stressed. The design allowed the joint to be made up to a final torque of 300,000 foot-pounds in about one and one-half rotations of the pipe. To keep the weight of the pipe string down, it was designed in six diameters varying from 15½ inches to 12¾ inches. The design also spelled out a protective outer coating—to prevent corrosion from degrading pipe strength—and a zinc coating on the threads to lessen the chances of thread galling and sticking.

b. **Construction**

The closest technology for the pipe string was that used in making 16-inch gun barrels for battleships. Since battleships were resting in their Valhalla, there was no current 16-inch gun barrel activity to draw upon. But the Army did produce from their Watervliet Arsenal a metallurgist who knew gun barrel technology. The Army brought him to Washington on very short notice and, for him, no apparent reason. He was totally surprised when two CIA officers picked him up at the Pentagon and took him off for briefings. Perhaps he was thinking that the Agency was going to duplicate a circus feat and hurl agents, like cannonballs, into denied territory. After hearing a description of the AZORIAN program and the metallurgical problems, the Army metallurgist was very helpful, especially in the evaluation of the manufacturing process and the manufacturers to be used on the pipe.

The Hughes Tool Company sought out potential contractors to pour, forge, and trepan (cut the center hole in) the rough pieces. Hughes itself would do the final machining, coating, and proof testing. From the candidate steel companies, they chose (with Agency approval) (b)(1) obviously was not producing pieces of the required size, they were making smaller gun barrels and had the capability for making high quality steel. When it became clear rather early on that (b)(1) couldn't handle the entire load, Jorgensen Steel, with its forging plant in Seattle, was brought in. Later on, as the pressures on the production schedule increased, a third company, National Forge in Erie, Pennsylvania, was hired to complete the production run. These three companies ultimately delivered a total of 590 rough-machined forgings in 30-foot lengths.

The steel selected to furnish the high strength was formally called AISI 4330V (mod.). This meant that it was a standard, well-known alloy steel that was modified by the addition of vanadium. Vanadium was added to give the proper strength, ductility, and toughness properties to the steel. Its minimum yield strength was 125,000 pounds per square inch. There was much concern over the ability to make forgings of the size required and at the same time maintain uniformity of material properties throughout the forging. The forging process was followed closely by Hughes, Agency engineers, and metallurgical consultants who were hired for their expertise.

Nothing about this single-thread failure mechanism was taken for granted. Several one-eighth scale pieces of pipe were made and subjected to scaled model tests.

The testing machine was computer-controlled with a program that mimicked the load condition imposed on the pipe by ocean forces. The goal of the test program was the completion of four life-cycles of testing without indications of fatigue cracking in the specimen. Each life-cycle was defined as 340,000 individual load cycles, which was equivalent to 940 hours of operation. During testing six life-cycles were successfully completed before fatigue cracking began. These results indicated a high probability that the pipe would successfully survive the estimated operational time (testing plus mission), which was 250,000 cycles or 690 hours.

The final, full-scale proof test of the heavy lift pipe further demonstrated the "take nothing for granted attitude." After Hughes had finished the final machining, coating, and color coding for size, they also subjected each piece to a proof test of 125% of its maximum expected load. This meant that the largest pieces would be loaded to 21,460,000 pounds. To do this required the design and the construction of a special proof test machine for the Hughes facility in Houston. Battelle Memorial Institute in Columbus, Ohio, designed and supervised the construction of the machine. It was the largest tensile test machine ever built. On 30 January 1972 the design engineer with much trepidation initiated the first full-load test of the pipe and the machine. Neither failed. Nor did they ever fail, even once, during the tensile testing of the 584 finished and delivered pieces (Figures 26 and 27). This was a fine tribute to the design effort and the quality control that went into the production of the pipe string. As the pieces were completed in Houston, they were assembled into 60-foot doubles and loaded on rail cars for shipment to the HGE (Figure 28).

The only refurbishment the heavy lift pipe required for MATADOR—the second mission—were the inspection and retorquing of the joints made up at the factory, and the repair of some minor corrosion pits on the threads.

c. **Pipe String Technology and Cost**

The forgings, from which the basic pieces were cut, were the largest members ever produced to such high strength, ductility, and fracture toughness requirements. Stringent metallurgical controls and inspections were required throughout the manufacturing process. The large pipe threads had a unique design which accommodated a high-load capacity simultaneously with a quick make/break connection. The proof test machine was the largest in the world. It had a maximum load capacity of 24,000,000 pounds.

The pipe string was designed, built, tested, and delivered in a 29½ month period from 29 May 1971 to 15 October 1973. Forging and machining required 21½ months, testing 8 months, and deliveries took place over the last 7 months. All pieces were at the pier well before the first sea trials took place in January 1974. Total costs, including the proof test machine, were (b)(1)

Data Handling

A relatively small but important item was the data processing system. It was developed by the Marine System Division of Honeywell, Inc. under a covert contract from the U.S. Government. Honeywell had other key parts of the AZORIAN hardware, including the station keeping and the sonar systems, but they were done as subcontracts to Global Marine and Lockheed. The main requirement on the data processing system was to have all the data logging and retrieval plus the control of the HGE and the CV operated from a single, centrally located computer facility. The system that was developed was a complex multicomputer system used for both on-line control of shipboard machinery and off-line data processing functions. The system

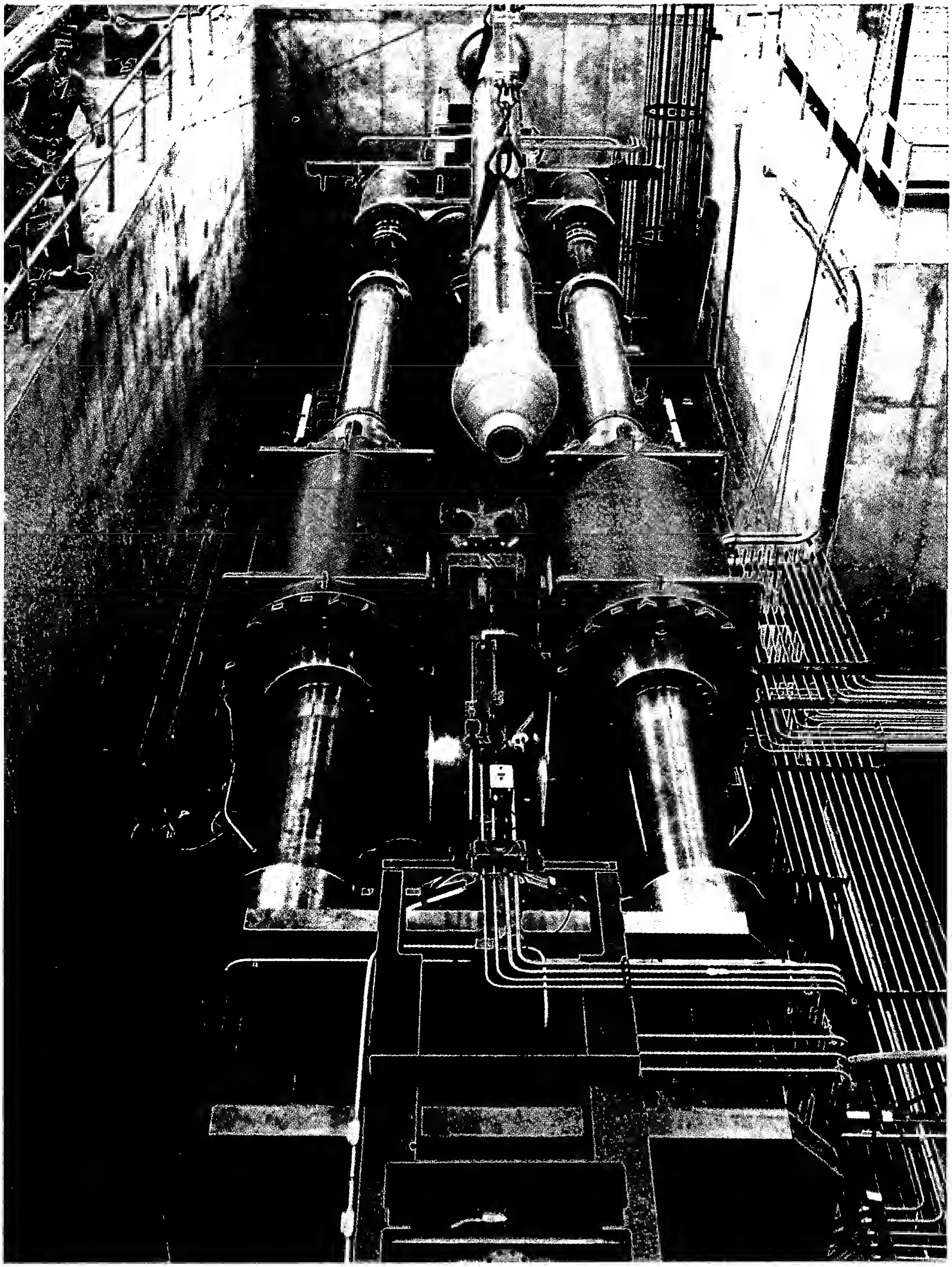


Figure 26. Piece of pipe being lowered into the proof test machine

Figure 27. The Dutchman, first piece of pipe in the string, under load in the proof test machine

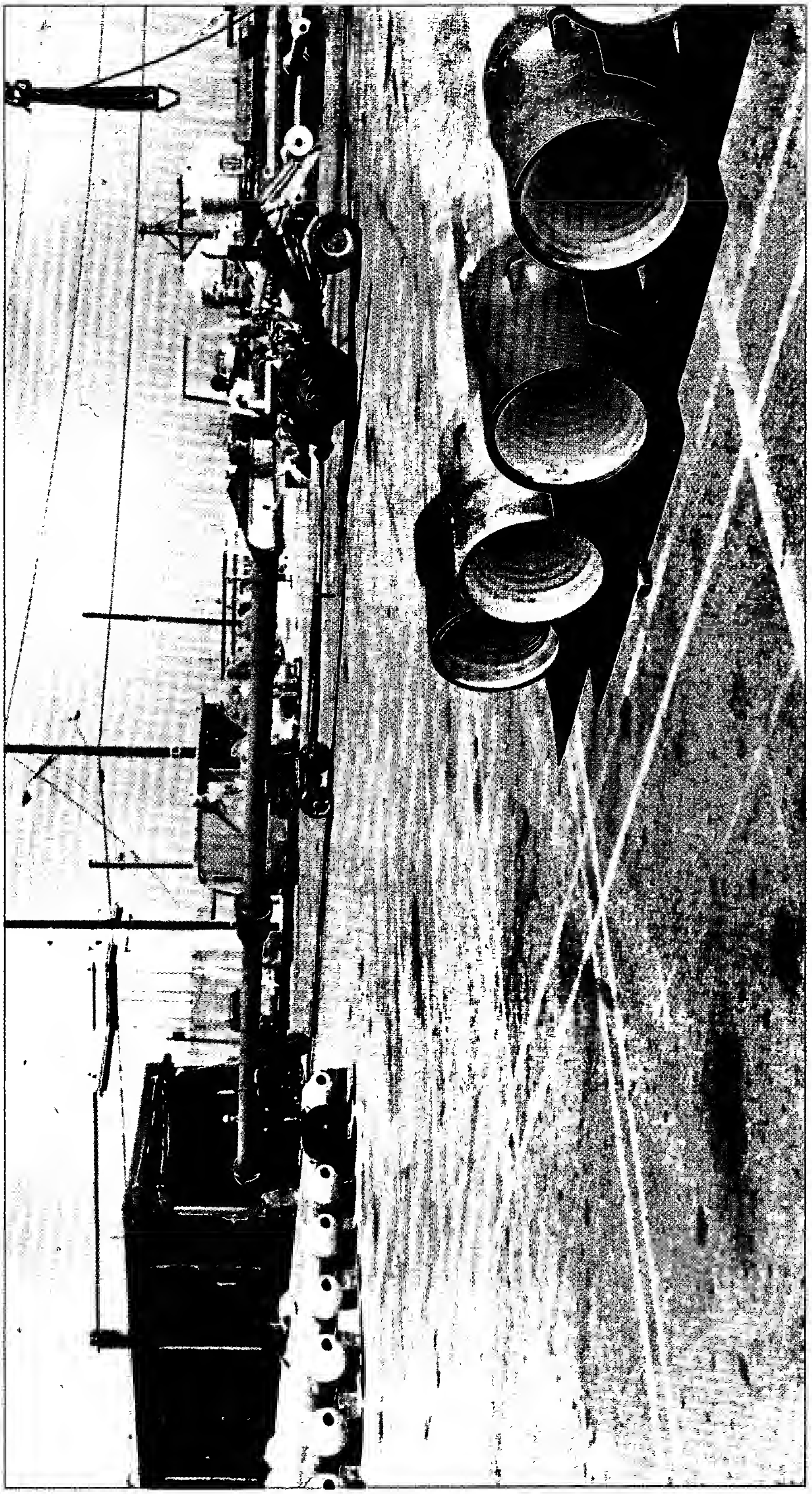


Figure 28. Pipe at Pier E showing pipe assembled into doubles 60 feet long. Threads are coated with a titanium dioxide/silicon oil coating to prevent seizure.

consisted of six ruggedized computers each with 32K of core memory, along with various peripherals such as magnetic tapes, disk packs, alphanumeric CRT displays, card readers and punch, line printers, and plotters.

Primary functions of the system were control of vessel position (automatic station keeping), coordinated control of underwater machinery, and data logging and retrieval. For example, the automatic station keeping routine used data from the heavy lift system and the ship's basic instrumentation to calculate the movements required to position the ship correctly in relation to the target. The results of these calculations could be fed directly into the ship's controls, causing the ship to maneuver without the laying on of human hands.

Of special interest were the operational support programs. One was used to help track the intelligence material retrieved from the target. Another was a weather applications program which predicted the response of the HGE and CV as well as the stresses in the heavy lift pipe resulting from weather induced sea conditions. Still another program calculated the adjustments needed in the anchor chains of the HGE to align her over the HMB-1 for mate/demate operations. This was undoubtedly the most precise four-point moor of any major ship.

A training simulator was built as a part of the data processing system. It consisted of a movable array of lights and miniature TV cameras to represent those on the CV. A software program was developed to simulate motion, forces, movement, and other information that would be coming to the control center operators during the actual recovery operation. Using a model of the submarine wreck as a target, the AZORIAN control center crew developed and perfected procedures for the critical maneuvers required for set-down and target capture.

To summarize, the hardware and software system specifications for the data processing system were submitted on 30 November 1971 and approved on 12 January 1972. It took a period of approximately 19 months (23 May 1971 to 2 January 1973) to design, build, and deliver the system. It was delivered to the HGE while she was at the Sun Shipyard in Chester, Pa. The cost was (b)(1) The system required only general refurbishment in preparation for the MATADOR program.

Field Engineering

As engineers know, all the design and laboratory testing in the world cannot anticipate each and every problem that will surface when you "go to the field." It is here that Yankee ingenuity and Kentucky windage come to the fore. AZORIAN was no exception to this general rule. A few examples should make the point. Engineering purists may want to skip the next few paragraphs; those of a more practical bent will understand and should find beauty in them.

After the first deployment of the pipe string during integrated systems test off Catalina Island, some of the threaded joints connecting two pieces of pipe were frozen together. No amount of applied force from the shipboard detorquing machine could loosen the joints. The immediate problem was to devise a method to unscrew the pieces of pipe without damaging them. Next, the cause of the problem and a solution for it had to be found.

A retired Navy engineering officer solved the immediate problem. He quickly designed what was probably the world's largest and strongest spanner wrench. (Figure 29 shows the super wrench in action.) Made from high-strength steel and operated with a manual hydraulic jack, Super Wrench could deliver one million foot-pounds of force to the pipe joints. This force plus a judicious heating of the outer surface of the

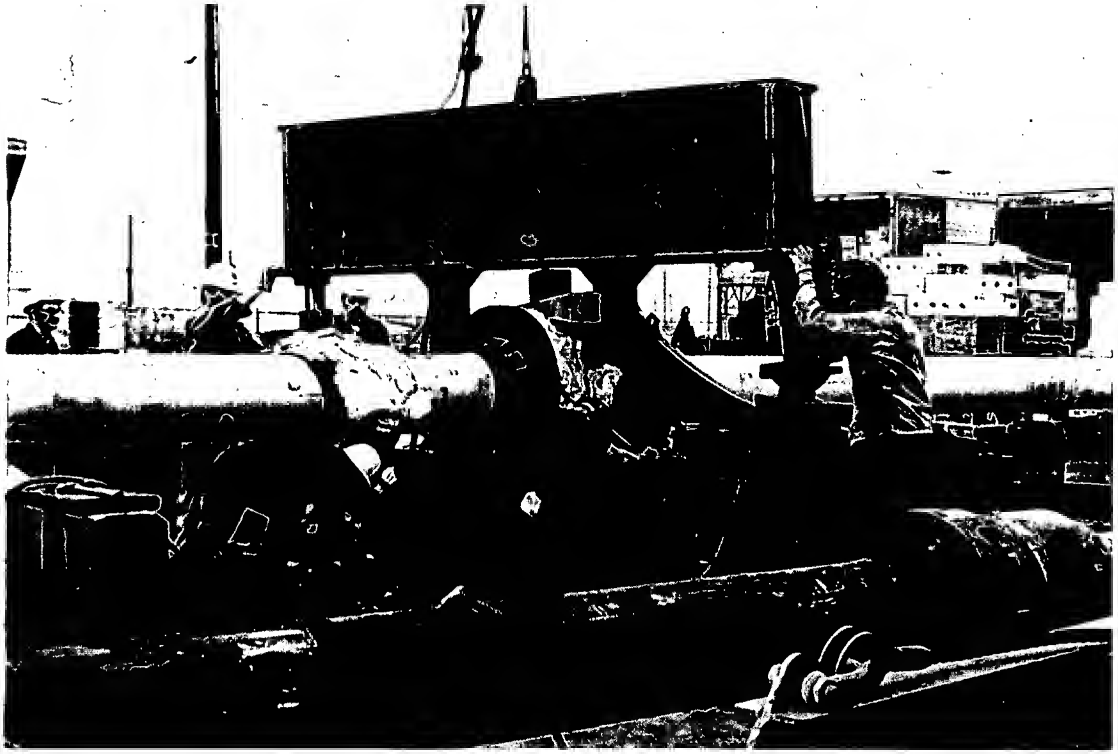


Figure 29. Super wrench being readied to free a stuck joint

pipe joint produced the desired effect with no serious damage to the threads (Figure 30).

As for the cause of the problem, it was determined that inadvertently a natural battery had been built into the threaded joint. The surfaces of the thread were coated with zinc and then covered with a normal oil field lubricant to prevent galling and sticking. Red lead was a constituent of the lubricant, and this together with the zinc formed the two opposing plates of a battery. All that was needed to complete the battery was an electrical conducting medium to connect the two. Even with tightly threaded pipe joints, enough sea water was forced into the joint to provide the electrical path. The resulting corrosion caused the threads to lock.

Immediate testing of alternate lubricants was started. One, a very sticky, gooey synthetic called Aqua-Lube, proved to have insufficient holding power. The final solution was a witches' blend of titanium dioxide, silicon dioxide, and zinc chromate in a silicone oil. After testing on the one-eighth scale model pipe, this new lubricant was used successfully on all the joints—but only after each full-scale joint had been thoroughly cleaned of the red lead and Aqua-Lube mixtures, perhaps one of the messiest jobs mankind has ever undertaken (Figure 31).

Another and quite different problem occurred during the operation in which the HGE picked up the capture vehicle from the submerged barge. In the program jargon this exercise was called mating. Not only was there an engineering mating taking place, but unbeknown to the ship's crew there was a biological mating taking place, too. The squid had returned to Catalina for their annual frolic in the shallow waters of Isthmus Cove (Figure 32).

Figure 30. Examining red lead coated threads for damage

After the capture vehicle was securely stowed within the HGE and the well gates shut, the pumps started removing the water from the well. This lasted only a short while; the pumps were constantly clogged with ecstatic squid, and no headway could be made in removing the water. Finally, the HGE was moved out of the cove to deeper water, the gates reopened, and lights hung over the side (it was the middle of the night) to draw the squid out of the well. Light seems somehow to discourage encounters of the sexual kind. Out came the squid; the gates were reclosed, and the pumps were free of squid except for a very few stragglers. There had been no text book solution available to the engineers for this problem. It was an exercise left entirely to the reader.

One last example from the mission will show still another form of engineering fixes—using a man to replace a device. Two large cylindrical devices called heave compensators absorbed the up-and-down motion of the sea and kept the rig floor (the pipe deployment area) at a constant level. These shock absorbers were located under the rig floor, fore and aft, and had a total stroke of 14 feet. It was critical that they move in unison, for if they got out of synchronization, the rig floor would be canted, not only causing metal-to-metal contact (and damage) but also putting a severe strain on the deployed pipe string.

Devices called rotapulsers measured the amount of stroke in each of the heave compensator cylinders. The measurement in each rotapulser was made by a wire which was on a pulley and a distance counter. This information was constantly fed to the control center for the lifting operation and was used to automatically keep the two cylinders in synchronization. Various problems had been experienced with the rotapulser, but on one occasion during the mission the wires failed. The cylinders got

Figure 31. Applying Aqua-Lube to the threads. It didn't work and had to be removed.

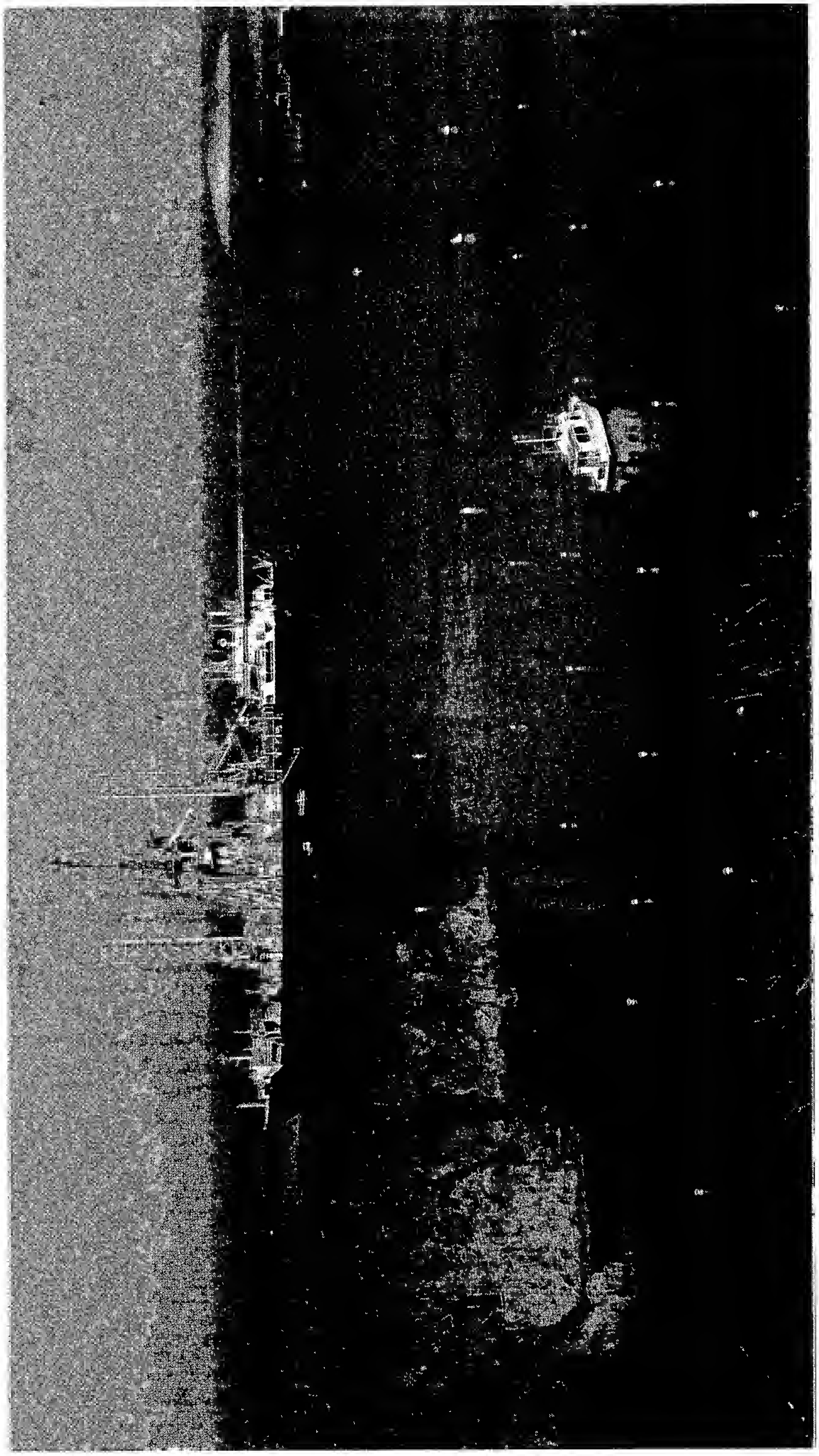


Figure 32. The HGE at the mating site at Isthmus Cove, Catalina. She is moored over the submerged barge HMB-1 whose support barge is just visible at the extreme right.

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out of "synch," and the resulting metal-to-metal contact caused an impressive display of sparks and noises as well as real damage. It was not a mission-ending failure, but because the operation was in a critical phase, it had to continue while the wires were replaced.

To gather the position information needed to keep the heave compensators in unison, a quite simple method was devised. Yardsticks were affixed to the ship near the moving cylinders and a welding rod was used as an indicator needle. One man with a headset telephone was stationed at each of the cylinders to read out the position of the rod on the yardstick as the cylinders moved up and down. The men at the other end of the phone in the heavy lift control center could then control the relative position of the two cylinders. It was a simple but effective solution to a nasty problem.

Later calculation showed that the wires failed at their predicted life cycle. The number of accumulated cycles on the wires had exceeded the original predictions—a small fact easily overlooked in the stress of solving larger and more pressing problems.

The Price Tag

Charges of exorbitant cost escalation have been levied on the engineering procurement for Project AZORIAN. The most critical one claimed that the Agency sold the program on the basis of a (b)(1) initial estimate. Charges such as this one were made without a careful examination of what actually took place. Here is the real history of the cost growth of Project AZORIAN:

a. **Fall 1969 and Spring 1970**–(b)(1)

The original concept used pentane tankage to provide buoyancy for lift and anticipated a total program encompassing three years. The recovery was to be performed covertly by means of specially constructed salvage barges with the target-lifting barge mated within a larger barge. The target was to be exploited in a safe harbor. No testing costs prior to the mission were included in this preliminary estimate. The earliest cost information included estimates of (b)(1) for design, (b)(1) for the barge and (b)(1) for operational costs the third year. Barge cost estimates were based on costs per pound for barge construction. Subsequent tank tests showed that interactions between the subsurface and surface salvage barges were impossible to control, and the use of pentane lift under these circumstances was too dangerous. The buoyancy concept was therefore abandoned.

These early estimates in the fall of 1969 totaled (b)(1). By the spring the complexity and problems associated with the buoyancy concept were more fully understood and a test program had been added. The dollar estimate increased to (b)(1) (b)(1). No attempt had yet been made to get program approval. The barge concept was not used but most importantly the program was not sold at this time with these cost estimates. Thus, the claims that cost growth estimates should use a (b)(1) base are erroneous.

b. **October 1970**–(b)(1)

The initial concept of a system for covertly lifting the target by the use of heavy lifting equipment mounted on a large surface ship had now been developed. Equally important, however, was the development of management and cover concepts using the image of Howard Hughes and the more plausible cover of a commercial deep ocean mining effort. These initially-estimated costs were based on incomplete data and on recovery projected for FY 1973. Estimates were obtained by scaling up the cost of an existing smaller vessel (the *Glomar Challenger*). The estimates totaled (b)(1) (b)(1)

On 16 November 1970 the procurement of certain long-lead-time equipment was authorized for the first time. Some people, therefore, argue that the (b)(1) estimate should be taken as the cost base. Those who would do that should remember that the initiation of procurement of long-lead items does not constitute a full program go-ahead. This type of procurement contract can be stopped with relatively small default penalties. Also there were still 11 major unknown or technical risk areas facing the engineers at this time. Resolution of these would almost certainly increase costs. Senior national-level management was advised of these, as was the ExCom. In fact, a five-month hold on major procurements was placed on the program two weeks after authorization for certain long-lead items was obtained.

c. **March 1971–** (b)(1)

During the period from October 1970 through March 1971 systems specifications and a total scenario for the project were being developed. The figure of (b)(1) was the first estimate given to ExCom based on preliminary engineering design studies and, as such, could be considered as a base cost reference point. Improvement of

(b)(1)

d. **August 1971–** (b)(1)

Estimates presented at the March 1971 ExCom meeting had listed a number of uncertainties and costs that further definition would refine. Based on a year-long detailed computer mensuration study of photography, it became apparent that the target was lying more nearly on its side than previously estimated, thereby increasing the effective width of the target. As described earlier, this required a significant redesign of the surface ship and capture vehicle. Additional cost growth was experienced due to strengthening of the lift shoulder of the pipe string. These cost increases caused the ExCom, in August 1971, to undertake a total review of the AZORIAN project and to order a moratorium on major procurement actions. The moratorium included deferring the keel laying of the surface ship. After a full review of target value, program costs, cover and risks, on 1 October 1971 the ExCom decided to proceed with the AZORIAN Project.

There were still a few uncertainties in the engineering areas: work needed to be done on the control system and the fail-safe portions of the heavy lift system; the grabber configuration on the CV was not finalized nor were the operator displays, the breakout legs, and the hydraulic system. The software for the computer system was just starting and simulation studies were still being run to determine operational red-lines for the equipment.

Since ExCom decided finally to proceed with AZORIAN and the keel was laid in November, the dollar estimate at this time, (b)(1) could serve as the cost base. The keel laying was a most significant event. It would be difficult to explain stopping ship construction after this occurred, and cancellation now would be costly in both a dollar and a credibility sense.

e. **April 1972–** (b)(1)

Contracts were made definite with the four prime contractors. The new program increases derived from funding required for engineering change proposals, proof-test equipment, increased costs associated with the construction barge, and increases to cover post-acquisition handling. An argument can be made that the basis for cost growth should be taken from this base, at which the contracts were made definite.

At this time also a major program review was undertaken by the Special Projects Staff in order to remove any "gold plating" from the hardware or any other aspect of the project. There was great pressure to make an attempt to keep the total costs under $200 million. At the same time, ExCom again reviewed and approved the continuation of AZORIAN.

f. **August 1972—** (b)(1)

This increase was caused principally by structural modifications to the surface ship needed to meet U.S. Coast Guard specifications, which were prerequisite to obtaining cover-related maritime risk insurance. The overall costs were estimated as follows:

Hardware	(b)(1)
Cover/Support	
Operations	

A furious debate was going on at this time over AZORIAN. A strong effort was mounted by senior Navy and Defense Department officials to kill the program. ExCom decided to go to the 40 Committee for a political assessment on running the operation in 1974. The upshot of all this was that President Nixon wrote a letter praising the project and approving its continuation. All debate on AZORIAN ended.

g. **October 1974** (b)(1)

The final hardware aquisition costs of Project AZORIAN totaled approximately (b)(1) They were broken down as follows:

Surface Ship System	**Dollars—Millions**
Heavy Lift System	(b)(1)
Docking Legs	
Spares	
Basic Surface Ship	
Capture Vehicle System	
Capture Vehicle	
HMB-1	
Data Processing System	
Pipe String System	
Special Purpose Vans	
Total	

Other costs associated with the total progr

Mining Machine	
Cover/Support	
Operations	

These brought the total costs for AZORIAN to (b)(3)(c) as of October 1974. An additional (b)(3)(c) was spent through October 1975 on preparations for MATADOR and program phaseout. The overall costs for the six and one-half year project were (b)(3)(c)

h. **Summary**

There are five points in time in the AZORIAN program that could be used to establish a cost base on which to calculate cost escalations. Of these five, two are really not valid. The first estimates of late 1969 and early 1970, in fact, are meaningless. They were based on a concept that wasn't used, and no program approvals or decisions were made on their merit. The charge that AZORIAN was sold as a (b)(3)(c) project is thus without foundation. The next estimate, (b)(3)(c) made in October 1970, also had little validity. It was made without having preliminary engineering or a total program scenario in hand. No major procurements were authorized; they were in fact expressly forbidden. Limited long-lead procurement was authorized at this time, but it cannot be said that full program approval was obtained.

The three remaining reference points, (a) March 1971 at (b)(3)(c) (b) August 1971 at (b)(1) and (c) April 1972 at (b)(3)(c) are valid, and arguments can be made for all three. Using the March 1971 date as a basis for cost, the escalation would be (b)(1)rcent; for August 1971, (b)(1)rcent; and for April 1972, (b)(1)percent (based on the costs of AZORIAN only). Of the three, the April 1972 date has the least persuasive argument for it. Although this was the time that the major contracts were definitized, all the important planning and engineering work that leads to a cost estimate had been done prior to this. The date is really a bookkeeping bench mark for finalizing contracts.

In the view of the project managers, the only valid dates for setting a base cost estimate are March 1971 and August 1971. By March a total scenario had been developed covering all essential elements of the program and the preliminary engineering had been completed. Although major long-lead procurements had been authorized, the ExCom had been made aware that significant engineering uncertainties remained and that their resolution could increase the costs. By August most of these solutions had been worked out and their price tags estimated; a major one was the required redesigning of the ship's hull. ExCom ordered the keel laying postponed until a thorough review was conducted, but the review was favorable and the keel was laid as planned in November 1971.

The estimate of (b)(3)(c) made in August 1971, then, is the best point from which to calculate cost escalation, for it was then that the ExCom authorized the keel laying, a momentous undertaking after which it would be difficult to abandon the ship construction. Calculating from this point, the cost escalation for AZORIAN registers as (b)(1) percent.

A Final Word

The equipment developed for Project AZORIAN lives on. After a short period in mothballs, the HGE was reactivated as an honest-to-goodness mining ship. A consortium led by Lockheed is using the ship and the pipe string to test a mining machine. Some tests have been completed and others are in the offing. The National Science Foundation is planning on converting the HGE to a deep ocean drilling ship. Their program is one to explore the ocean margins for scientific and economic purposes. It will be a large program carried out through 1989 with a cost in the neighborhood of $600 million.

The world's largest submersible (HMB-1) has been used by the Department of Energy in their ocean thermal energy conversion program. The San Francisco Bay base for the HMB-1 is being used by the U.S. Coast and Geodetic Survey as an operational location.

Recently, the Nuclear Regulatory Commission has made inquiries about using the proof test machine to test steel plate. Even a part of Clementine (the CV) has found use. One of her arms is part of a tensile test facility in Southern California.

The same technology developed for the AZORIAN simulator was used recently to construct a simulator to train operators to emplace a huge offshore oil platform. The platform, costing $750 million, was constructed in several hundred feet of water off the Lousiana Coast. In this way the training procedures and hardware developed for AZORIAN have played a role in helping to develop the oil resources of the United States.

So the labor of love created by a group of Agency managers and engineers has borne a continuing reward. Let us hope that Agency officials of the future will be blessed in kind.

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